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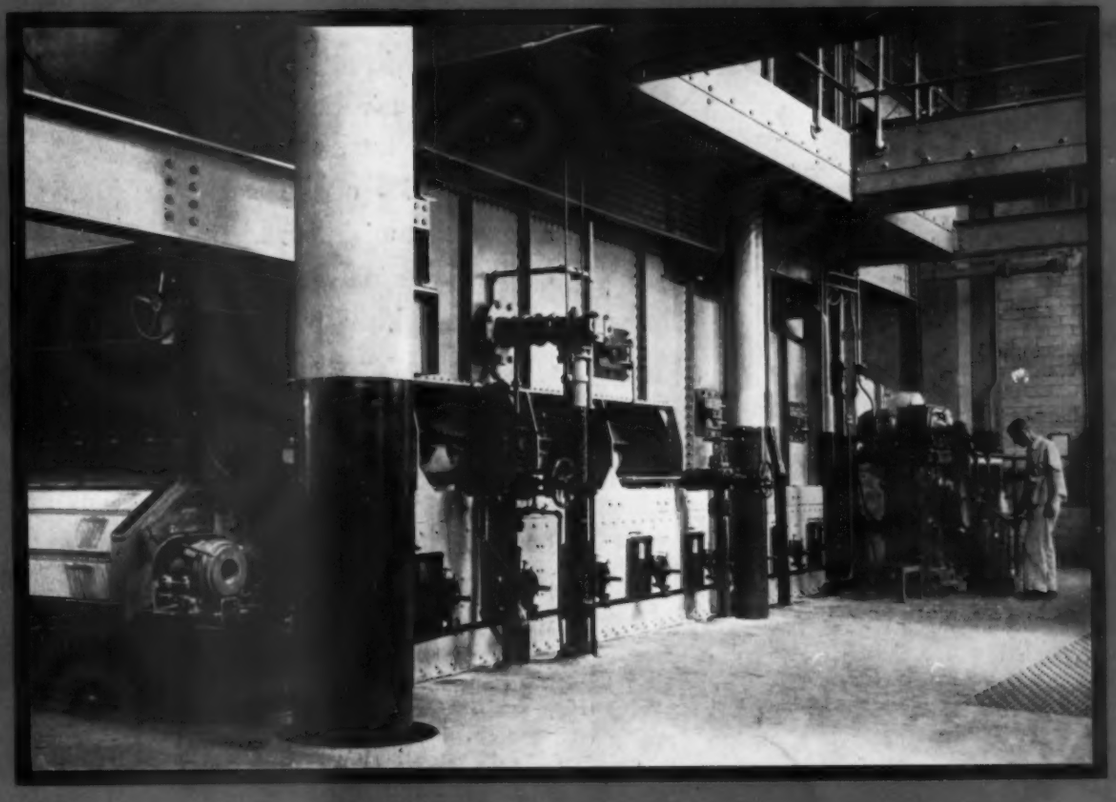

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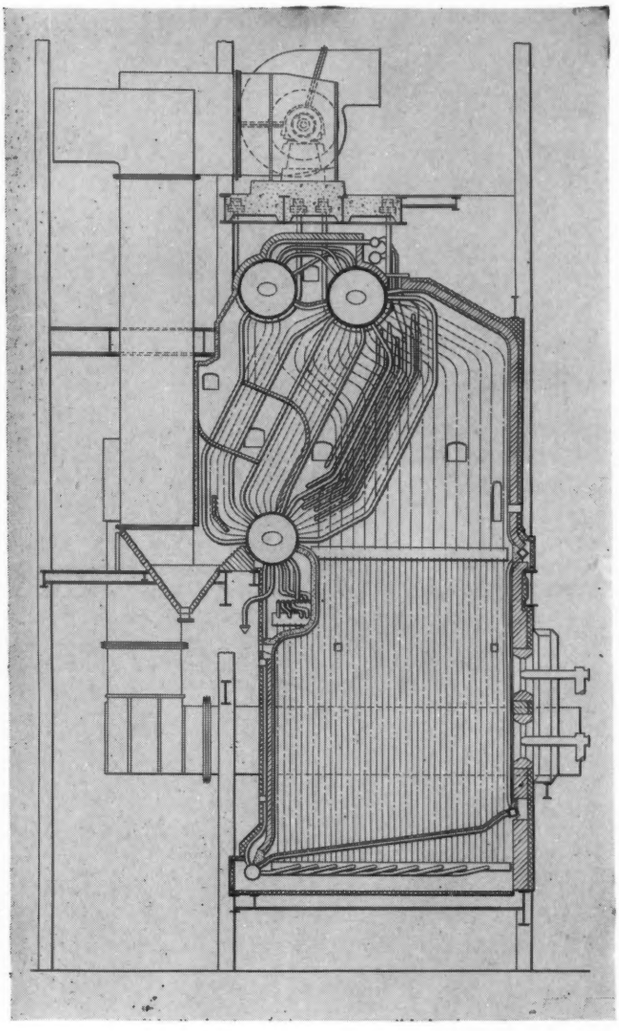

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME FIFTEEN NUMBER FIVE

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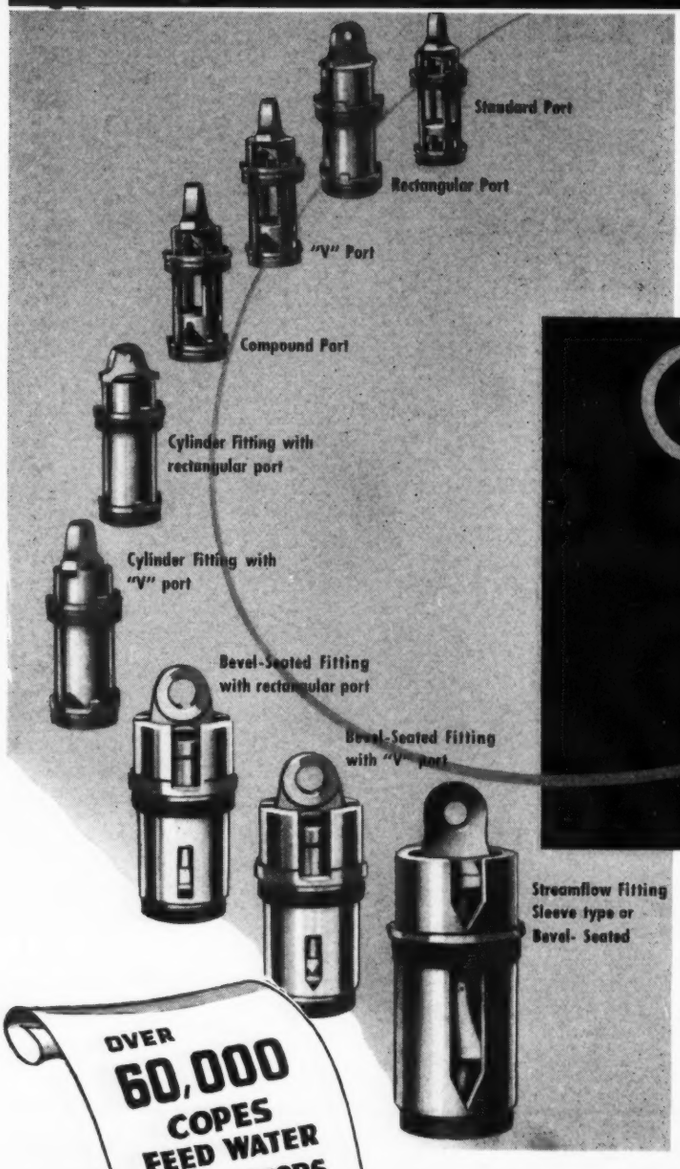

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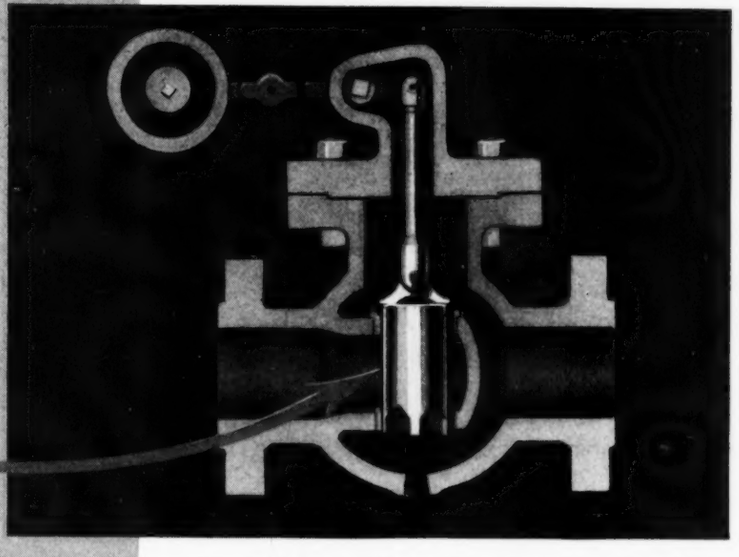

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EDITORIAL

Engineering Training Under Government Supervision

Needs of the Services for a vast number of men with specialized training and for technicians of various kinds are being met by courses set up under Government direction at many of our universities as well as at other training centers. These come under the Engineering, Science and Management War Training Program (E.S.M.W.T.) of the U. S. Office of Education. From all accounts, an excellent job is being done in so far as filling immediate needs. Over one and a quarter million technicians have been turned out since October 1940, and they are being employed in a vast number of activities associated with the war effort.

Also, upper classmen in engineering schools are being permitted and encouraged to finish under a speeded-up program.

In addition to the foregoing, with the dual purpose of avoiding a dearth of young engineers in the post-war period and of supplying the Armed Forces as needed, the Government is sending hundreds of recent high-school graduates, and those who will graduate within the next few months, to colleges and universities for intensive courses in various branches of engineering. These courses under direction of the Navy and the Army, range, in general, from twelve to thirty-six weeks. The Navy training program, known as N.C.T.P., involves curricula that differs only slightly from those of the regular accredited engineering schools. The Army training program, A.S.T.P., while not as complete, does afford a fair preparation to young men who otherwise would not receive any technical education.

Depending upon the duration of the war and future needs of the Armed Forces, many or few of those enrolled in these latter courses will see active service; which fact raises the question of how adequate their training may prove as preparation for post-war work.

It is true that much ground can be covered by intensive study over long hours for such a period, in contrast with the more leisurely pace of peacetime schedules; but one may be led to question the average student's ability to absorb and retain information gained through cramming, especially when only a limited time is available for drilling in fundamentals; for, in the final analysis, it is the grasp of fundamentals that counts.

It will be recalled that only a few years back some of our leading educators were proclaiming that the complexities of modern society rendered a four-year engineering course inadequate and advocated five or six years, embracing certain of the liberal arts. Although such a plan was adopted by only a few institutions, there resulted a widespread liberalization of engineering curricula with a trend away from specialization.

If this premise were correct, is it not reasonable to assume that the intensive speeded-up courses, now being prescribed for recent high-school graduates, will lead to the turning out of many "so-called" engineers inadequately prepared to tackle the problems of a post-war world, or to survive competition from the more experienced engineering minds released from war production and from the armed services. If so, a large number of those now being trained may find it expedient to drift away from engineering employment. Nevertheless, those of ability, whose interest in engineering has thus been whetted, are likely to take advantage of opportunities to return to college or, through the medium of evening instruction, to prepare themselves more effectively for greater usefulness when the war is over. Every encouragement should therefore be extended to those so inclined and it is not too early to give serious thought to this matter.

Less Coal Calls for Greater Vigilance

The several stoppages in coal mining during the present year are officially estimated to have resulted in an aggregate loss in coal production of approximately forty million tons at a time when a substantial increase over normal production was vital to the war effort. While this is the penalty that has been exacted by a policy of prolonged appeasement and political handling of the coal labor problem, recriminations at this time serve no useful purpose. The fact must be faced that there will be a shortage of coal for many months to come and that its price is certain to advance. Such being the case, every effort must be made to economize in its use and eliminate waste wherever possible to the end that all essential needs may be met.

Operation during war time is not always conducive to best economy, in view of the fact that shortage of new equipment has made necessary the use of many old, less efficient units and in some cases less experienced operators are running them. Nevertheless, it is often surprising what economies can be effected, particularly in industrial plants, when study is given to the scheduling of machine operations, to the proper loading of motors and a systematic search is made for all sources of waste. But what is everybody's job is nobody's job, and it becomes necessary to charge some competent individual in each plant with the duty of seeing that everything is done toward this objective. Moreover, he must be clothed with the necessary authority to enforce orders.

By such means only will it be possible to avoid serious consequences.

CORROSION BY HOT GASES

By RICHARD C. COREY

Combustion Engineering Company, Inc.

This article reviews briefly the concepts of the mechanism of metallic corrosion at high temperatures; it discusses the role of alloying elements added to iron, steel and copper to confer high temperature corrosion resistance; and presents some quantitative data on the rate of corrosion.

WHEN sustained metal temperatures exceeding 1000 F are required for service in contact with air, furnace gases or steam, plain low-carbon steel must either receive special surface treatment or be replaced by a more resistant metal or alloy. Inasmuch as surface-treated steels are limited in their application for high-temperature service, alloying elements such as chromium, nickel, aluminum and silicon, alone or in combination, are added to iron and steel to produce a wide variety of heat-resisting alloys. Other elements, such as molybdenum, tungsten, vanadium and titanium, also frequently are added to improve the tensile and creep properties and to prevent decarburization of the metal at operating temperatures. Such alloys find wide application in the power plant in superheater elements, fuel burners, bypass dampers and other components of steam-generating units that are subject to high temperatures and stresses. Also, in certain process operations which utilize low-pressure process steam at about 1400 F total steam temperature, the superheater materials usually contain high percentages of chromium and nickel. Obviously, further developments to improve the efficiency of the Rankine cycle through the use of higher steam temperatures and pressures than are used at present would require even greater use of alloy steels which must also have adequate physical properties at the service temperatures.

The mechanism of high-temperature corrosion is less well understood than that of corrosion by liquids.[1] In recent years, however, fundamental studies of the structure of the oxides formed on metals and alloys at high temperatures by means of petrographic and electron-diffraction techniques, and the determination of the rate of diffusion at high temperatures of metals in metals, gases in metals and metals in oxides, have led to rational explanations for certain high-temperature properties. The prudence might be questioned of expending money and effort to determine to the nearest hundredth of an angstrom unit the distance between atoms in the corrosion product on certain metals and alloys. Such fundamental work, however, is fully justified as it is leading to a better understanding of the rôle of alloying elements in conferring resistance to high-temperature attack with the result that the development and selection of metals for specific purposes will become less empirical.

The most important factor involved in the process of oxidation of a metal is *diffusion*, a physical mechanism which, in one sense, determines the interchanging of dissimilar particles under suitable conditions. A short discussion of diffusion at this point will aid in visualizing the mechanism of scale formation on heated metals.

Diffusion might be thought of thermodynamically as a physical process which tends to produce the maximum randomness of distribution of the particles in the system. Some of the more common examples of the effect of diffusion are to be seen in: (*a*) the gradual self-mixing of a salt if placed in water and allowed to stand quietly; (*b*) the self-mixing of two gases if stratified; (*c*) the passage of hydrogen through certain metals; (*d*) the case-hardening of steel; (*e*) the heating of castings at the proper temperature to produce a more uniform structure (homogenizing); and (*f*) the surface treatment of metals, such as galvanizing, calorizing, etc.

Diffusion Explained

Each of these processes involves the movement of an ion, atom or molecule, as the case may be, of one of the components through those of the other. For example, under suitable conditions, hydrogen diffuses readily through iron and steel. This is believed to occur as follows: At the surface of the iron certain forces are present which split the hydrogen molecule, H_2, into two hydrogen atoms which then pass between (interstitially) the iron atoms, or to be more exact, the iron ions comprising the iron lattice. (The term lattice denotes in a broad sense the geometrical arrangement of the unit particles in a solid.) In the case of the diffusion of one solid through another, the process involved in oxidation and scaling, the manner in which the movement occurs is more complicated and is now the subject of considerable study. A complete discussion of these concepts with particular reference to oxides on metals may be found in several recent articles.[2,3,4,5,6] For the present discussion it is necessary only to mention that metal ions[7] can diffuse through the oxide on the metal in two ways:

[1] See article by this author on "Corrosion by Liquids" in the August 1943 issue of COMBUSTION.

[2] "Oxidation of Metals and Formation of Protective Films," N. F. Mott, *Nature*, **145**, 996 (1940).

[3] "Mechanism of Movement of Ions and Electrons in Solids," C. Wagner, *Trans. Faraday Society*, **34**, 851 (1938).

[4] "The Transition State Theory of the Formation of Thin Oxide Films on Metals," E. A. Gulbransen, *Preprint* **83-4**, 1943, The Electrochemical Society.

[5] "Diffusion In and Through Solids," R. M. Barrer, Macmillan Co., 1941.

[6] "Diffusion und Chemische Reaktion in Festen Stoffe," W. Jost, Theodor Steinkopff, publisher (Germany), 1937.

[7] The unit particles of metals are believed to be positive ions rather than atoms; that is, the atoms are deficient in electrons. Oxides, however, are composed largely, though not entirely, of atoms. This explains the use of these expressions above.

(*a*) They can go into solution at the metal-oxide interface; moving between (interstitially) the atoms comprising the oxide. The concentration of metal ions decreases toward zero as the oxide-gas interface is approached thus producing a *concentration gradient* through the oxides; a factor which will be shown later to be important to the rate at which diffusion occurs.

(*b*) They can move into vacant positions in the oxide lattice. Compounds such as ferrous oxide (FeO), magnetite (Fe_3O_4) and cuprous oxide (Cu_2O) and ferrous sulfide (FeS), all of which can occur as corrosion products on the respective metals, belong to a class of compounds which contain less metal than corresponds to the stoichiometric formula. Iron sulfide, for example, has been found to vary in composition from Fe_5S_6 to $Fe_{16}S_{17}$.

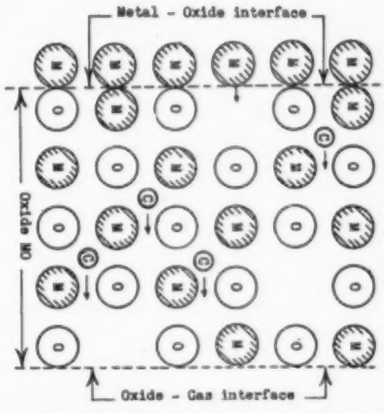

Fig. 1—Schematic two-dimensional view of crystal lattice of oxide MO, on metal M, in which some M atoms are missing; also, smaller atoms C are shown diffusing interstitially

The oxide FeO is known to be deficient in iron to the extent of 5–10 per cent. This means that there are vacant positions in the lattice of these compounds corresponding to the missing metal atoms, with the result that metal ions of the base metal on which an oxide or sulfide has formed can move into the vacant positions, thus leaving other vacant positions into which yet other atoms can move. These two processes are shown schematically in Fig. 1.

The rate of diffusion in solids is based upon Fick's Law, derived by analogy to the flow of heat through solids. An excellent discussion of the derivation and modifications of this law is given in the literature cited.[5,8] In general, this law states that the amount of material diffusing (solute) in unit time through another (solvent) is proportional to the area times the concentration gradient of the solute in the solvent. The proportionality constant is the *diffusion coefficient*, a factor which has been determined for a great number of systems. It is important to note that the diffusion coefficient varies greatly with temperature; the higher the temperature the greater the rate of diffusion with other things equal.

Mechanism and Rate of Scaling

Fundamentally, the rate of high-temperature oxidation, or sulfidization where sulfur gases are involved, of metals such as iron, copper, and their alloys is dependent upon the rate that metal ions meet the gas atoms and combine to form an oxide or sulfide. Formerly it was believed that the gas diffused interstitially through the existing oxide until it reached the metal-oxide interface and progressively oxidized the metal. Numerous experiments with iron and copper by various investigators, notably Pfeil[9,10] who studied iron and steel, have shown that it is the metal ion that diffuses through the oxide to the oxide-gas interface. Chemical analyses at various distances through the cross-section of the scale formed on iron in air showed progressively lower percentages of iron as the outer surface of the oxide was approached. Thus a concentration gradient of metal ions exists through the scale, a factor mentioned above as being important to the rate of diffusion.

Theoretically, it is improbable that an oxygen atom can diffuse interstitially through a compact oxide because of its relatively large diameter with respect to the distance between the atoms in the oxide. It is possible, however, for a small amount of oxygen to be taken into solid solution in the oxide but the extent and depth to which this occurs is negligible. Thus, it may be inferred that the progress of scaling occurs by new scale forming on the outside of previously formed scale as the result of metal ions diffusing to the surface, by either mechanism described above, to meet and react with the gas atoms, and not by new scale forming at the metal-oxide interface and gradually forcing the first-formed scale outward.

The rate of scaling is of three types.[4,11] In cases where the scale has a higher specific volume than the metal from which it was formed, it is likely to be porous and gas atoms may diffuse through the pores and reach the metal. Likewise, alternating stresses or thermal shocks in the metal may cause cracks and fissures in the oxide through which the gas will have free access to the metal. Under these conditions the rate of oxidation occurs linearly with time, or,

$$y = k_1 t$$

where y = thickness of scale, k_1 = a constant for the conditions under which oxidation is taking place, and t = time.

In cases where the specific volume of the oxide is less than that of the metal, resulting in a compact oxide, the rate of the growth is parabolic and,

$$y^2 = k_2 t$$

The oxidation of iron, stainless steel, and copper follows this law for certain temperature ranges, and it is of interest to note that the calculation of the rate of oxidation of these metals leads to a parabolic expression if one assumes that only the metal ions diffuse outward through the scale in the manner described above.

When metals such as aluminum, chromium and zinc are oxidized at temperatures below 300 C the rate of scaling follows a logarithmic relation, namely,

$$y = k_3 \log t$$

Aluminum has been found to oxidize very rapidly ini-

[8] "Diffusion in Solid Metals," R. F. Mehl, *Trans. A.I.M.M.E.*, **122**, 11 (1936).

[9] "The Oxidation of Iron and Steel at High Temperatures," L. B. Pfeil, *Journal Iron & Steel Inst.*, **119**, 501 (1929).

[10] "The Constitution of Scale," L. B. Pfeil, *Journal Iron & Steel Inst.*, **123**, 237 (1931).

[11] "Laws Governing the Growth of Films on Metals," U. R. Evans, *Preprint* **83-10**, Electrochemical Society, 1943.

tially and to cease when an oxide only 100 atoms thick has formed.

Composition of Oxides on Heated Metals

The oxidation of iron in air yields a scale that consists of three separate phases[9,10] as illustrated in Fig. 2.

Nearest the metal is a phase known as *wüstite*, of the nominal formula FeO, which contains 75 to 77 per cent iron by weight. It is a solid solution of limited range of Fe in Fe_3O_4. Equilibrium studies of the iron–oxygen system show that wüstite is not stable and under conditions of slow cooling, in the absence of stabilizing elements, it will decompose to an eutectoid of Fe and Fe_3O_4 below 570 C. The middle phase consists primarily of *magnetite* (Fe_3O_4) which is strongly magnetic and contains 72.3 per cent iron. Crystallographically magnetite is a spinel, a spinel having the general formula

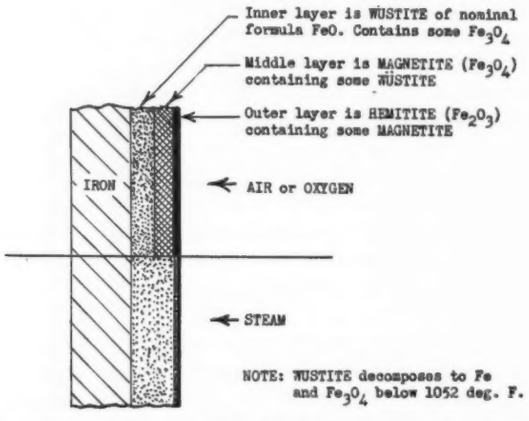
Inner layer is WÜSTITE of nominal formula FeO. Contains some Fe_3O_4
Middle layer is MAGNETITE (Fe_3O_4) containing some WÜSTITE
Outer layer is HEMITITE (Fe_2O_3) containing some MAGNETITE
IRON
AIR or OXYGEN
STEAM
NOTE: WÜSTITE decomposes to Fe and Fe_3O_4 below 1052 deg. F.

Fig. 2—Schematic view of oxide phases on iron showing their relative thickness, according to whether oxygen or steam is in contact with the metal

$$M''O \cdot M_2'''O_3$$

M'' being a divalent and M''' a trivalent metal atom. In the case of magnetite these are both the same atom. Properties of the spinel type oxides are important to the diffusion mechanism as it has been shown that where the metal atoms are different the rate of diffusion of metal ions through the oxides is inhibited, whereas in the case of magnetite diffusion is relatively rapid. The outer phase is Fe_2O_3, a reddish-brown, non-magnetic oxide containing 70 per cent Fe which crystallographically is the same as hematite.

The relative proportions of these oxides vary according to conditions, but where plain carbon steel or iron oxidizes in air between about 1200 and 1800 F the wüstite will be about 50 per cent, the magnetite 40 per cent and the Fe_2O_3 10 per cent of the total scale thickness. In steam, the wüstite comprises 95 to 98 per cent of the thickness of the scale. When SO_2, SO_3 or H_2S is present in the gas, iron sulfide (FeS) may be found in the scale.

In iron-nickel alloys the oxide consists chiefly of wüstite in which small globules of a nickel-rich, nickel-iron alloy are distributed. Extremely high rates of oxidation and intergranular attack leading to embrittlement occur when nickel or iron-nickel alloys are exposed to sulfur gases. A eutectic comprising 0.01 per cent sulfur in solid solution in nickel[12] and Ni_3S_2 is formed which melts at the relatively low temperature of 1100 F. High chromium concentrations, however, modify the eutectic, raising the melting point and permitting the use of nickel where the concentration of sulfur gases is appreciable, as in refinery practice.

In iron-aluminum alloys which have oxidized slowly the oxide consists of alumina (Al_2O_3). Where the rate of oxidation is high, the scale consists of alumina distributed in iron oxides, possibly as the spinel $FeO \cdot Al_2O_3$.

There is no general agreement as to how the phases are distributed in the scale on iron-chromium alloys but there are indications that chromium oxide (Cr_2O_3) tends to concentrate in the innermost iron-oxide phase and prevents the diffusion of iron ions.

The iron-chromium-nickel alloys, which comprise the greatest percentage of the corrosion-resisting alloys, either as ferritic or austenitic types, form scale which appears to be strongly stabilized by the presence of a spinel type of oxide of the formula $NiO \cdot Cr_2O_3$.[13] This is an example of a spinel in which the metal atoms are different and therefore it has a higher resistance to diffusion than magnetite.

In the iron-silicon alloys containing more than 2 per cent Si it appears that an iron oxide-iron silicate eutectic phase concentrates in the innermost oxide layer through which silicon diffuses at a slow rate.

In the case of copper, electron-diffraction studies[14] have shown that cuprous oxide (Cu_2O) occurs close to the metal, and cupric oxide (CuO) comprises the outermost phase. When oxidized in air the Cu_2O is approximately ten times thicker than the CuO. Beryllium, magnesium and aluminum confer good resistance to high-temperature oxidation of copper. Each of these elements, as an oxide, is found in the outermost part of the scale. A recent article[15] indicates theoretically, based upon the structure of these oxides and the relative atomic diameters, that these elements should form protective oxides.

Before presenting quantitative data on the effect of the composition of the metal or alloy, and the atmosphere with which it is in contact, a few basic procedures in corrosion testing will be discussed briefly.

Corrosion Testing

Corrosion tests are made with two major objectives: (*a*) to obtain fundamental information on the mechanism of corrosion, and (*b*) to obtain quantitative data that will aid in selecting a suitable metal for a certain engineering application. Subsequent discussion will refer to the latter objective.

Corrosion tests may be conducted in the laboratory on a small scale where every effort should be made to simulate service conditions and to control closely the variables which affect the corrosion rate. Frequently tests are made under actual service conditions, in which case, certain of the variables cannot be controlled. In most cases it is preferable to study the metal under both con-

[12] "Metals Handbook." American Society for Metals, 1939 Edition, p. 1636.
[13] "Resistance to Furnace Atmospheres of Heat Resisting Steels," A. Quarrell, Special Report No. 24, Iron & Steel Inst., 1941.
[14] "Cuprous-Cupric Oxides on Copper," C. Cruzan and H. Miley, *Journal of Applied Physics*, **11**, 631 (1940).
[15] "Oxidation Resistance in Copper Alloys," L. Price and G. Thomas *Journal Inst. Metals*, **68**, 21 (1938).

ditions and, if agreeable correlation of the data is obtained, one may be reasonably sure that the conclusions drawn therefrom are valid.

The following rules should be observed in corrosion testing, particularly with reference to laboratory studies, if reproducible results are to be obtained:

(*a*) The test should not be an *accelerated* one. The practice of making accelerated tests in order to obtain the results in a short time has been responsible for more useless corrosion data than any other factor. Accelerated tests require that one or more of the variables be intensified with the result that the relative effect of the variables may be considerably different from that under actual service conditions. There are certain special property tests such as corrosion-fatigue tests, season-cracking tests and impingement tests, which in a sense are accelerated tests, but in the hands of a careful investigator, who is fully aware of their applicability, they are extremely useful.

(*b*) The composition and heat-treatment of the specimens should be known and should be identical with that of the metal whose corrosion properties are desired.

(*c*) The surface condition of the specimens should be similar to that of the material to be used in practice. Frequently, however, it is advisable to prepare the surface by degreasing, removing scale, etc., in acid, rinsing thoroughly, and abrading it lightly with a fine emery cloth. The details of such treatment should be reported with the data.

(*d*) The temperature must be controlled closely.

(*e*) The composition and the rate of flow of the corroding medium must be known.

(*f*) The area of contact of the specimen with the support should be a minimum as it is at this point that corrosion attack often begins with the result that attack on adjacent areas may be accelerated or retarded.

(*g*) The shape of the specimens should be similar to that of the service part; that is, it is preferable to use cylindrical rather than flat specimens if the service part is to be a bolt or rod.

(*h*) The period of exposure should be standardized. Inasmuch as the rate of corrosion generally occurs parabolically with time a one-hour test of a metal at a certain temperature will give a higher result for the corrosion rate than a twenty-four hour test. There is considerable disparity between the results reported in the literature for the corrosion rate of mild steel in air. For example, Fig. 3 shows data selected from the literature[16,17,18] and some unpublished work of the writer which have been placed on the same rate basis, namely, "inches penetration per year." The corrosion rate above 1500 F is seen to be progressively higher as the duration of the test is shortened. Wherever possible, it is desirable to conduct a test on the material at constant temperature for varying periods of time in order to determine the relation of corrosion rate to the period of exposure.

(*i*) In order that the data be comparable with those of other investigators, the corrosion rate should be expressed in terms of the amount of metal lost per unit area per unit time or as the depth of penetration per unit time. The two most frequently used units employed in this country are "milligrams per square decimeter per day" and "inches penetration per year." The use of "per cent loss of weight" without specifying the exposed area and weight data is not desirable. Although the rate units mentioned imply that the amount of corrosion varies linearly with time, a rather limited case if the test is conducted for a sufficiently long period of time, and the period is specified, no serious error is introduced.

Another expression that is used for corrosion rate is "weight increase per unit area per unit time." The increase in weight represents the amount of oxygen or sulfur that has combined with the iron and it can be expressed in terms of the amount of metal corroded *only* if the chemical composition of the scale is known. In the case of the oxidation of iron or steel one may assume the scale to contain an average of 75 per cent iron but at best this gives only an approximate result. Where the time and facilities permit, it is always advisable to remove the scale chemically by methods described in the literature.[19,20]

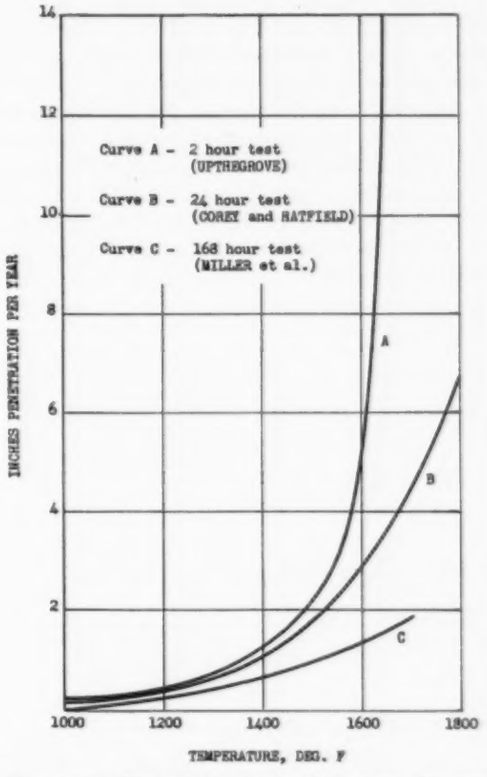

Fig. 3—Showing effect of duration of test on the corrosion rate of low-carbon steel in air

It may be inferred from the foregoing statements that efforts should be made to standardize corrosion procedure as it is only when this is done that the engineer may be assured of reasonable values for the service life of a metal under given conditions. However, experience has shown that attempts to standardize are beset with many diffi-

[16] "The Scaling of Steel at Heat-Treating Temperatures," C. Upthegrove, *Engineering Research Bull.* 25, University of Michigan (1933).
[17] "Heat-Resisting Steels," W. Hatfield, *Journal Iron & Steel Inst.*, 115, 483 (1927).
[18] "Alloy Steels for High Temperature Service," R. Miller, G. Smith, and P. Jennings, *Metals and Alloys*, September and November 1942.
[19] "Removal of Corrosion Products from Iron," T. Finnegan and R. Corey, *I.E.C., Anal. Ed.*, 5, 89 (1933).
[20] "Corrosion of Unstressed Steel Specimens and Various Alloys by High-Temperature Steam," H. Solberg, G. Hawkins and A. Potter, *Trans. A.S.M.E.*, 64, 303 (1942).

culties; but one may devise a reasonable test procedure if the factors mentioned are considered.

Effect of Metal and Gas Composition

In all of the data here presented the writer has calculated the published results of the several authors to a common basis by means of the factors shown in the Appendix.

In Fig. 4 is shown the effect of steam, air, oxygen, sulfur dioxide and carbon dioxide on low-carbon steel at temperatures between 1300 and 1800 F. It should be noted that below 1300 F the effect of these gases is approximately the same. Small amounts of water vapor in oxygen, air, CO_2 or SO_2 will accelerate the attack to a greater degree than occurs with these gases alone. Also, these gases in mixtures will not corrode the metal in proportion to their relative amounts.

The effect of oxidation in air on alloy steels is shown in Fig. 5. Chromium in excess of 3 per cent markedly increases the resistance to corrosion and small amounts of silicon in addition are definitely beneficial. It should be noted that molybdenum, which frequently is added to these alloys, does not improve the corrosion resistance and serves only to increase the resistance to creep of the alloy at high temperatures.

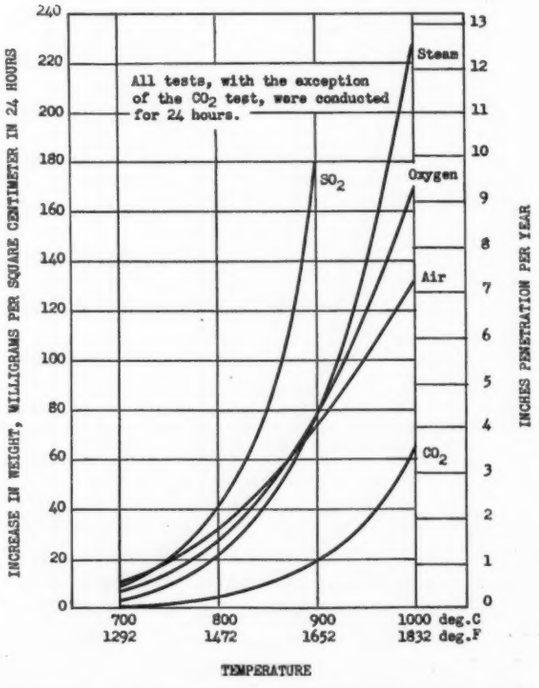

Fig. 4—Corrosion rate of 0.17 C steel in various gases (calculated from data in references 16 and 17)

The action of steam on steel is not, as thought by many, due to the oxygen available from the thermal decomposition of steam at high temperatures. Calculations from water vapor equilibrium data show that the partial pressure of oxygen from this source in 1000 F steam is too low to account for the rapid attack of steel at temperatures of this order. The reaction that takes place is one in which a new equilibrium

$$3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + H_2$$

occurs. At moderate temperatures the rate of this reaction to the right is governed by the thickness and compactness of the oxides on the metal. However, when the temperatures are very high the rate of diffusion of iron through the scale becomes the controlling factor and the thickness of the scale is of less importance. Also to be considered is the effect of alternating thermal and mechanical stresses in the metal which tend to cause fissures through which the steam can reach the metal and the rate of attack changes from a parabolic to a linear relation with time.

A comprehensive research project[21] to study the effect of high-temperature steam on alloy steels has been in progress in this country since 1937. The effect of steam

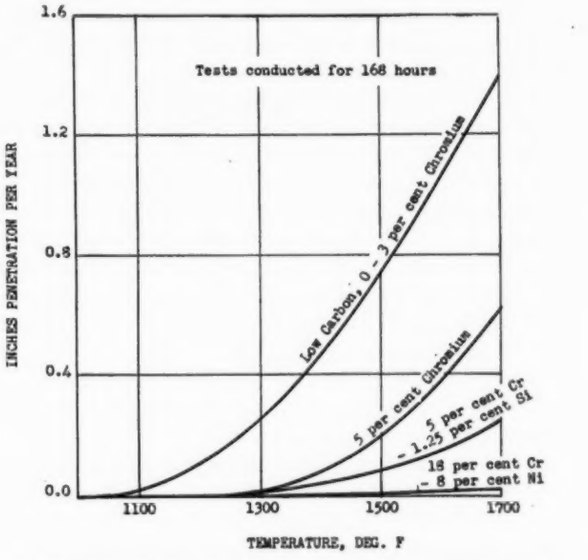
INCHES PENETRATION PER YEAR
Tests conducted for 168 hours
Low Carbon, 0 - 3 per cent Chromium
5 per cent Chromium
5 per cent Cr - 1.25 per cent Si
18 per cent Cr - 8 per cent Ni
TEMPERATURE, DEG. F

Fig. 5—Corrosion rate of various steels in air (average of data of Miller, Smith and Jennings)

between 1000 and 1200 F on unstressed alloy steels is shown in Fig. 6. More recent work has extended these data to 1800 F and the relative effect has been found to remain as shown in the figure.

A European investigation[22] of the same problem shows essentially that maximum corrosion resistance was obtained with 15 to 17 per cent chromium steel, 18 per cent chromium-8 per cent nickel steel and high silicon-chromium steels.

Alloying Elements

The purpose of the various elements added to heat-resisting steels may be summarized as follows:

CHROMIUM—This offers excellent resistance to oxidation, depending upon the amount present which may vary from 1 per cent to 28 per cent. It improves resistance to the effect of sulfur gases.

SILICON—Used alone in steel silicon offers only moderate resistance to oxidation, but in combination with up to about 5 per cent chromium, it affords high resistance

[21] "Investigation of the Oxidation of Metals by High Temperature Steam," A. Potter, F. Solberg and G. Hawkins, *Trans. A.S.M.E.*, **59**, 725 (1937); **64**, 303 (1942); **65**, 47 (1943); **65**, 301 (1943).

[22] "Choice of Materials Resistant to Corrosion Under Superheating Conditions in High-Pressure Boilers," 33 E. I. Schmanenck, *Khim. Referat. Zhur.*, 1, No. 7, 106 (1938); q.v. *C. A.*, No. 17, 6778 (1939).

to oxidation. It appears also to improve resistance to sulfur attack of chromium-nickel alloys.

ALUMINUM—Used alone in steel, aluminum offers only moderate resistance to oxidation, but about 0.5

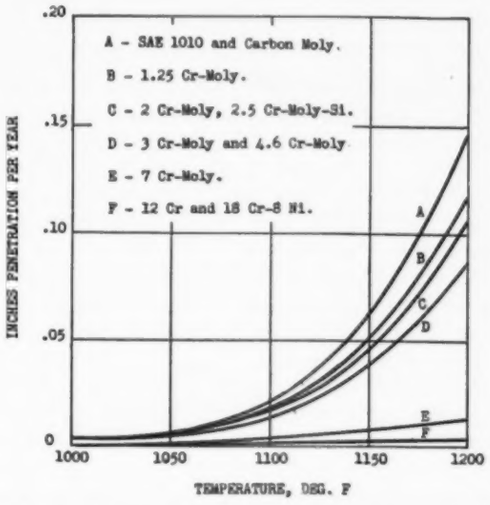

Fig. 6—Corrosion rate of various steels in steam for 500 hr at various temperatures (Solberg, Hawkins and Potter)

per cent Al in chromium, and chromium-silicon steels, improves the resistance to oxidation of these alloys.

NICKEL—This is not notable for improving the oxidation resistance when used alone in steels, but in combination with chromium, it provides very high resistance to oxidation and good load-carrying ability. It is very susceptible to sulfur attack unless an appreciable amount of chromium is present.

MOLYBDENUM—This is added primarily to improve creep resistance of steels that are intended to operate at high temperatures.

The nominal alloy content of a few commercial heat-resistant steels and the approximate temperature to which they are effective follow:

Chromium	Nickel	Silicon	Aluminum	Molybdenum	Effective to
1-3%	..	1%	...	0.5%	1200 F
5%	..	2%	0.5%	0.5%	1500 F
5-10%	..	2%	0.5%	0.5-1%	1750 F
17%	..	..	..	...	1650 F
18%	8%	..	..	...	1750 F
28%	12%	..	..	...	1750 F
25%	20%	..	..	...	2000 F

It should be borne in mind that corrosion resistance is not the sole criterion of the suitability of an alloy for use at high temperatures where tensile or bending stresses are present. The alloy must possess, in cases where clearances are small, adequate creep resistance, and tensile and fatigue strength at the maximum operating temperature. Neglect of these factors may vitiate otherwise inherently good corrosion properties of the metal.

For certain high-temperature work, where stresses are not excessive, it is economical to employ ordinary steels that have been treated to obtain a corrosion-resistant skin on the metal by means of a process known as "cementation." This is a process which produces a thin layer of an alloy on the surface of a base metal such as steel by placing it in contact with another metal, in a finely divided condition, and heating for a long period at elevated temperature; metal to metal diffusion effecting a bond between the two metals. The thickness of the layer formed may be 0.005 to 0.050 in., depending upon the type of coating desired, and the temperature and time of the process.

The most widely used cementation process for improving the resistance to high-temperature corrosion, is known as "calorizing." The metal to be treated is placed in a hermetically sealed box with aluminum powder, aluminum oxide and a small amount of ammonium chloride. Maintaining an inert or a hydrogen atmosphere, the box is rotated and heated to from 1500 to 1800 F for 12 to 48 hr. The aluminum forms a solid solution alloy of aluminum and iron that diffuses to a depth of 0.025 to 0.040 in., and which will stand 5 per cent elongation without damage.

Other methods for producing such a coating include hot-dipping followed by heating for a long time in an inert atmosphere to permit diffusion to take place at the iron-aluminum interface.[23] Under ordinary conditions, steel can be used to as high as 1650 F if the surface is properly prepared. Tests[24] of calorized carbon-molybdenum steel have shown promise for its use for pressure parts that will be required to operate up to a temperature of 1200 to 1300 F.

Silicon and chromium (ihrigizing and chromizing) have been used in a similar manner to that described above, the former conferring good resistance between 1200 and 1600 F.

APPENDIX

FACTORS TO CONVERT CORROSION DATA FOR IRON AND STEEL TO "INCHES PENETRATION PER YEAR"

Units Given			Factor = Inches
Weight Loss	Area of Specimen	Time ×	Penetration per Yr
Grams*	Dm†	Hr	4.40
Grams*	Dm†	Day	0.183
Grams*	Dm†	Week	0.026
Grams*	Dm†	Month	0.006
Grams*	Cm†	Hr	440.0
Grams*	Cm†	Day	18.3
Grams*	Cm†	Week	2.6
Grams*	Cm†	Month	0.6
Grams*	In.†	Hr	68.2
Grams*	In.†	Day	2.8
Grams*	In.†	Week	0.4
Grams*	In.†	Month	0.09
Pounds†	In.†	Hr	31053.0
Pounds†	In.†	Day	1292.0
Pounds†	In.†	Week	184.0
Pounds†	In.†	Month	42.5
Pounds†	Ft†	Hr	215.8
Pounds†	Ft†	Day	89.8
Pounds†	Ft†	Week	12.8
Pounds†	Ft†	Month	2.95
Thousandth of an inch penetration per hour			8.76
Milligrams‡ increase in weight per cm.† per day			0.055

* When the loss of weight is given in milligrams instead of grams, divide the factor shown by 1000.

† When the loss of weight is given in ounces instead of pounds, divide the factor shown by 16.

‡ This factor is based on assumption that the scale is an oxide and contains an average of 75 per cent iron.

[23] *Metals Handbook*, p. 1082.

[24] "New Alloy Pearlitic Steel for High Temperature Service," C. Clark and R. Brown, *Trans. A.S.M.E.*, **59**, 541 (1937).

Joint A.S.M.E.-A.I.M.E. Fuels Meeting Considers Research and Post War

APPROXIMATELY four hundred representatives of coal producers, combustion engineers and power plant men met at the William Penn Hotel, Pittsburgh, on October 28 to attend the two-day conference of the Fuels Division of the A.S.M.E. and the Coal Division of the A.I.M.E. This was the seventh annual conference of these groups and this year post-war fuel problems and research dominated the program.

Following an address of welcome by **H. M. Moses,** president of the H. C. Frick Coal Company and response by **Harold V. Coes,** president of the American Society of Mechanical Engineers, the opening session on Thursday morning was devoted to coal research. Two papers—"Progress of Research in Coal Utilization" by **E. R. Kaiser** of Battelle Memorial Institute, and "Test Methods for Rating the Performance of Domestic Stoker" by **R. Helfinstine,** of the Illinois Geological Survey, were followed by a Panel Discussion on "Selling Coal Research and Its Products."

In the absence of Mr. Kaiser, his paper was presented by **A. W. Thorson.** This reviewed the five-year program of research inaugurated by Bituminous Coal Research, Inc. and thus far carried on at Battelle Memorial Institute, Columbus, Ohio, at Carnegie Institute of Technology and at the University of West Virginia. Among the subjects covered by this long-range program are improvements in domestic heating; industrial heating furnaces; the control of fly ash, smoke and slagging with industrial stokers; new designs of coal-fired steam locomotives to improve their competitive position with diesel-electric locomotives; complete gasification of coal; the conversion of industrial furnaces to pulverized coal; over-fire air jets; the direct production of power from coal in internal-combustion engines; and better mining methods, including cleaning and dustless treatments of coal. Inasmuch as future coal reserves lie in the higher sulphur regions, this subject will be studied as will also coal transportation to avoid degradation and windage losses of fine sizes.

Present expenditures are at the rate of $85,000 per year but it is hoped to increase this to $500,000 per year.

The suitability of coals for domestic stokers, according to Mr. Helfinstine, depends upon more than the amount of heat that can be obtained from a pound of coal, other controlling factors being the uniformity of heat release, the responsiveness of the fire, the convenience of operation, smoke density and ability to hold the fire. The author reviewed the test methods set up to determine these factors and presented some excellent colored motion pictures showing coke and clinker formations.

At the Panel Discussion, led by **J. E. Tobey**, of the Upper Monongahela Valley Association, **H. N. Eavenson,** president of Bituminous Coal Research, Inc., told of the progress in securing the necessary funds and backing to undertake the present research program. Under the agreed plan the coal industry is to contribute at the rate of 1/4 cent per ton of coal produced for a period of five years and this is supplemented by contributions from the railroads and other sources. He listed, in order of importance, the various projects that were to be undertaken.

Points stressed by several others taking part in the discussion were (1) that small-scale laboratory research is ideal in that one factor at a time can be studied; (2) that the more easily solved problems should be taken up first in order that definite results may sustain the interest of those making financial contributions to the program; (3) that in selling research to the average business man the problem should first be carefully analyzed; (4) that coal preparation is of paramount importance to the central-station industry; and (5) that in order to interest the most desirable research workers they should be assured of a future in industry.

Australian Coal Supplies

At the Luncheon following this session **H. F. Hebley,** Director of Research of the Pittsburgh Coal Company, told of his recent visit to New South Wales under the jurisdiction of the Board of Economic Warfare and the Petroleum Administration. Australia, he said, has vast coal deposits aggregating about one-fifth those of the United States and ranging in rank from the very best grades to a low-grade brown coal. It has practically no oil. The mines are all owned by the Government, as are all public utilities, and due to a labor government and union influence mechanization of the mines is prohibited. This has proved a considerable handicap in view of the present man-power shortage.

Long-Range Fuel Policy Advocated

The Thursday afternoon session included papers on "Modern Training for the Miners at the Face," by **G. R. Spindler** of the University of Virginia, and "Coal Faces Post-War Adjustment," by **R. M. Weidenhammer** of the Cosgrove Coal Company. Mr. Weidenhammer advocated a long-range national fuel policy as a post-war necessity in the interest of the public as well as of both the coal and the oil industries. Commenting on the essentials of such a policy, he said:

"Coal is the predominant source of heating fuel. How soon we will have to depend almost exclusively on it for heating depends on how much oil and natural gas we still can add to our present dwindling supplies. Some day, to be sure, coal will have to carry the full load. If the coal industry is to be ready to do this job and to do it well and to do it under a free enterprise system, two questions naturally arise:

"(1) Are the companies getting a fair profit, that is, enough to plow back some of it to expand production and open new mines when the old ones are exhausted,

and to pay dividends to attract new investors if and when additional capital should be needed?

"(2) Can the miners expect steady enough employment to encourage their sons to step into their fathers' trade?

"The answer to both questions is obviously no. Quite obviously also, a solution must be found, and it appears that World War II has in at least two ways done its part to indicate the direction in which such a solution will be found. It has warned the nation of the danger of relying for heat on oil that some day will be unavailable.

"Extensive use of coal as a raw material for motor fuel in this country may be a century off. But the use of fuel oil for heating purposes—and today over 40 per cent of crude oil production is so used—will come to an end in perhaps less than a decade. The sooner the oil industry concentrates on motor fuel, the higher will be the financial return to the oil companies on their present reserves of crude oil and or whatever exploration will add to their reserves."

"We coal people realize with pride how coal provides more than twice the output of oil. We also must view with alarm the industry's failure twice this spring to avoid strikes when everybody should have put his shoulder to the wheel. Responsible people will cast no doubts as to our patriotism, but these strikes were just plain bad business. They constituted a real factor why Congress refused the extension of the Coal Act of 1937 in spite of the plea of labor and of most of the operators. Loss of coal production, which cannot be made up, has meant that the rationing of coal had to be discussed and that the Government has stopped, in many cases, advising the use of coal instead of fuel oil. Thus, the greatest opportunity the industry has had in over twenty years to regain its old markets and to enjoy the good will of the nation has received a serious setback.

"The proved resources of only 3.2 billion equivalent tons of natural gas, 415 billion tons of petroleum, and 21 billion tons of shale oil are very small compared to a total of 2559 billion equivalent tons of bituminous coal. Of course, more petroleum and natural gas will be discovered, but we do not know how much or how soon they will be found. The known petroleum reserve of about 20 billion barrels is of about the same order of magnitude on a heating-value basis as the known reserves of natural gas. The shale-oil reserve in the United States is four to five times the known petroleum reserve. It is estimated at 92 billion barrels of oil.

"Consumption of crude oil in this country rose from 3 gal. per capita in 1900 to 425 gal. in 1940. But of this only 180 gal. were used as motor fuel, to drive some 30,000,000 cars and trucks an average of 9000 miles a year. Soon after the war more cars and trucks than ever will be on the road and people will drive more miles a year than ever before. We will also have airplanes and a seven-seas navy to enforce the peace. We will have more planes to transport people and goods. The oil industry faces this record demand with a shrinking amount of production and shrinking total reserves.

"What is the choice of permanent policies that Congress can adopt?

"(1) Permanent nationalization of the mines. Such a solution cannot be reconciled with the American conception of free enterprise system. Furthermore, such a solution is no solution at all. It would simply make the taxpayer assume the losses suffered by the coal operators in competition with other fuels and would therefore inevitably lead to agitation for the nationalization of the competing fuels.

"(2) Complete status of laissez-faire. This is what the industry has had since August 23, 1943. Once the war demand for coal subsides, this status of free competition will probably put most of the operators into the red and throw more labor out of a steady job. It would put such pressure on the price of coal and on the wages of the miners that both the industry and the U. M. W. might come near being wrecked, and Congress would then be asked to devise a new scheme.

"(3) Self-regulation. Any scheme of self-regulation of the industry would, to be effective, run afoul of the Department of Justice and the Supreme Court. Even if Congress should exempt the industry from the anti-trust laws, any scheme of production or price control would sooner or later be up against two problems: Chiselers in our own ranks and competition from other fuels.

"(4) Federal regulation. Federal regulation of minimum prices expired on August 23. It never had to stand the test of a declining market. If minimum prices were to be reintroduced in a depression, production control might have to be added to make price control stick. The red tape of price control was bad enough; production control would at least double it. Any such solution would put the coal industry on stilts or, probably more to the point, into an oxygen tent. Such a solution would keep the coal industry alive at the expense of the consumers. It would deprive the industry of the elbow room necessary to defend itself effectively against the encroachments of other fuels.

"With the Coal Act of 1937 just a memory, the coal industry, in working out its future, will have to start again from scratch. This is quite an advantage, if it is to approach the problems of the post-war period with an open mind and with old grievances forgotten."

Coal-Oil Mixtures

Subsequent technical sessions included papers on Producer Gas and Coal Carbonization, and at the final session on Friday afternoon, **J. F. Barkley** of the U. S. Bureau of Mines reported on "Laboratory and Field Tests on Coal-in-Oil Fuels" in a paper in which **A. B. Hersberger** of the Atlantic Refining Company and **L. R. Burdick** of the Bureau of Mines collaborated. This paper covered laboratory studies on the stability of coal suspensions in oil, the mixing of pulverized coal and oil and field tests at the Atlantic Refining Company's Philadelphia Plant, at the Cambria Silk Hosiery Company and at the National Airoil Burner Company, on such mixtures in typical oil-burning equipment.

The laboratory studies indicated that best results could be expected when using bituminous coals (low specific gravity) and oils of high specific gravity and high viscosity, and that a sufficiently stable suspension of the coal in heavy oil could be obtained by dispersing 40 per cent of coal, by weight, ground to 98 or 99 per cent through a 230-mesh screen.

Experiments were made with a number of stabilizers.

Of those tried, lime-resin soap (one per cent) was found unsatisfactory, and 1 to 1½ per cent of sulphuric acid, applied to the coal surfaces before mixing, gave the best results. Also, coal tar when used as 10 per cent of the oil mixture showed stabilizing action. However, none was as effective as fine grinding, and the sulphuric acid involved the disadvantage of probable corrosive action.

It was found in the field that the mixing of the coal and oil did not present much difficulty, a simple batch-mixing device being employed with an oil temperature of 75 to 120 F maintained by steam coils in the tank. The fuel was circulated for about 12 hr.

As would be expected, the characteristics of the mixture were different from those of the oil. It was about 10 per cent heavier per unit of volume; it was 4 to 8 times as viscous; more abrasive; and any settling out of coal resulted in pasty accumulations in various parts of the equipment.

A standard steam-atomizing burner handled the mixture satisfactorily, although about two-thirds more atomizing steam was required than with oil alone, and the boiler efficiency was slightly less. While considerable smoke was produced when starting up a cold furnace, no smoke difficulties were experienced after attaining full operation. Such ash as accumulated in the furnace was readily removed.

No settling or clogging was experienced in the pipe lines from tank to pump and to burner, despite the relatively long pipe lines with the fuel at elevated temperatures; but there was appreciable accumulation of coal-oil paste in the heater in the trials with less finely ground coal. Moreover, there was some clogging of the meters and screens.

The main pumping problem was from storage tank to the pump; after the fuel had been heated in the heater it was not difficult to pump. It was found that coal-oil mixtures require heating to temperatures of 140 to 170 F to give about the same viscosity as that of oil at 100 F. It is necessary to avoid these higher temperatures in the storage tank in order to minimize settling. Hence, close attention must be given the pumping of coal-oil mixtures, particularly where underground storage tanks are employed.

A high spot of the conference was the banquet on Thursday evening. **T. E. Purcell** acted as Toastmaster and addresses were given by President **Harold V. Coes** and **Col. James Walsh,** U.S.A. retired, who gave an inspiring talk on some logistic problems of the war.

Presentation of Percy Nicholls Award

The dinner was the occasion for the presentation of the Percy Nicholls Award to **Henry Kreisinger,** Manager of Development and Research, Combustion Engineering Company, Inc., for "his contribution to the organized study of coals of the United States; his research work in the utilization of solid fuels; his contribution to the science of fuel technology; and to the development of the safe and economical use of pulverized fuel." This award, which was presented by **W. G. Christy,** is named for the late Percy Nicholls, for a number of years supervising fuel engineer of the U. S. Bureau of Mines. In accepting the Award, Mr. Kreisinger reviewed the early history of coal research in this country, his remarks, in part, being as follows:

Organized study of coals started at the Coal-Testing Plant built for that purpose at the St. Louis Exposition in 1904. It appears that the United States Geological Survey had completed a study of the coal deposits in the United States, covering the location and extent of the deposits and the rank of the coal. There seems to have been a feeling that it was desirable to test these coals to determine their fuel value for various uses. It was, therefore, decided to build the Coal Testing Plant with sufficient equipment to test these coals in steam boilers, gas producers, coke ovens, a coal washery and a coal-briquetting plant. The results were published in a number of reports. The Coal Testing Plant was operated by the Technologic Branch of the U. S. Geological Survey. This was probably because the Geological Survey has made a survey of the coal deposits and it was only natural that the coal tests which were intended to determine the value of these coals for certain uses were more or less considered a part of the original survey of the coal deposits. As the work of testing proceeded it was found that the methods used were quite different from those employed in the surveying of the coal deposits, and, therefore, a special bureau was created in 1910. This bureau was designated as the Bureau of Mines which concerns itself with the mining and the utilization of the coals of the United States.

Henry Kreisinger was born in Radnice, Czechoslovakia, in 1876 and was naturalized in Chicago in 1898. He received the degree of Bachelor of Science in 1904 and the degree of Mechanical Engineer in 1906 from the University of Illinois. Previous to joining Combustion Engineering Company, he was engineer with the U. S. Geological Survey in St. Louis and Pittsburgh; fuel engineer with the Clinchfield Fuel Company, Spartanburg, South Carolina; and fuel engineer with the U. S. Bureau of Mines in Pittsburgh, in charge of fuel investigation.

The Chanute Medal was awarded to Mr. Kreisinger in 1907 by the Western Society of Engineers for a paper prepared in collaboration with W. T. Ray, which is believed to have presented for the first time an analysis of the influence of gas flow on heat transmission.

Mr. Kreisinger is the author of some 70 technical articles and papers. He has patents or patents pending on a great number of fuel inventions, such as boiler and furnace installations, driers, economizers, a dust collector, a fuel handling system and a fuel pulverizing system. He has done important constructive work on committees of the A.S.M.E., A.I.M.E., American Gas Association and other groups.

Inasmuch as by far the largest part of the coals is used for making steam, only the results of steaming tests will be considered in this discussion.

After about 400 steaming tests had been made on widely different coals from almost every part of the United States, and varying in rank from North Dakota lignite to New River coal, the results were then tabulated and plotted in ways to facilitate a study of the value of these coals for steaming purposes. This study revealed that the efficiency obtained with the various coals was practically constant and that the amount of steam that could be made was directly proportional to the heat value

of the coal. All that was necessary to determine the amount of steam that could be made with any given coal in any given boiler was to ascertain its heat value by means of a calorimeter. The efficiency that could be obtained depended on the design of the boiler in which the fuel was burned. In other words, the designer fixed the efficiency when he designed the boiler.

We know today that it is possible to design a steam generating unit that will give 70, 80 or 90 per cent efficiency, according to the amount and kind of heating surface and its arrangement in the path of the hot gases. While today these statements are very much a matter of indisputable facts, it was different 40 years ago when much less was known about the performance of steam boilers. It was then thought that by some mysterious manipulation known only to a few experts, high efficiencies could be obtained regardless of the boiler design.

Chemical Analysis and Heat Value Sufficient

The conclusions that were deduced from the study of these 400 steaming tests led to important changes in the methods of testing fuels. Instead of running boiler tests to determine how much steam could be made with a given coal, all that was necessary was to determine its heat value in a calorimeter. Therefore, the testing of the coals was centered largely in the chemical analysis of the coals and in the determination of their heat value. This testing work done in the chemical laboratory was supplemented by a study of the fundamentals of combustion of coal and heat transmission applied to steam generating apparatus. These studies were conducted with specially designed apparatus which made it possible to obtain accurate data. This apparatus was designed with the idea of varying only one factor at a time while other factors were held constant. Up to that time furnaces consisted of a grate. Combustion space was not deemed important and was never mentioned in reports of boiler tests. Studies were, therefore, directed to the processes taking place within the fuel bed and in the combustion space. The results of these studies along with the chemical analysis supplied more useful information about the use of fuels than an ordinary boiler test could produce.

The heat transfer, as applied to steam boilers, was also studied. Heat is transmitted to the heating surfaces by radiation and convection; conduction comes into play after the heat has reached the heating surface. The laws governing these modes of heat transfer were studied and the results were published in some of the technical papers issued by the Coal Testing Plant. Thus, the Coal Testing Plant became an important factor in collecting and disseminating useful knowledge pertaining to the functioning of the steam boiler.

Effect of Mass Flow Demonstrated

If we examine some of the textbooks or periodicals of that period we find very little information on heat transfer as it is understood today. The effect of mass flow on heat transfer by convection was practically unknown, and it was believed that the heat transfer was proportional to the difference of the squares of the temperatures. This, I believe, was a compromise between the heat transfer by radiation which varies as the fourth power of the absolute temperature and the heat by convection which varies as the first power of the temperature difference.

The study of the fundamentals of combustion and heat transfer supplied information for the design of boilers and furnaces and the selection of coal-burning equipment.

During the steaming tests and the subsequent study of the fundamentals of combustion it was found that a large part of the difficulties in burning coal were due not so much to the chemical composition of the combustible matter, but to the presence of ash. Today we know that about 75 per cent of our troubles in burning coal are due to the presence of ash. It is not a question how well the combustible burns but what is the behavior of the ash; will it form bad clinkers in the fuel bed, or plaster with slag the heating surfaces of the boiler and superheater, thereby choking the gas passages? Therefore, within recent years the study of the use of coal has been directed toward the composition of the ash, its fusion temperature and its behavior in the furnace. When we wish to form an opinion about the suitability of a given coal for a given coal-burning equipment, we desire to have not only the chemical composition and heat value of the coal but also the fusion temperature and perhaps the composition of the ash.

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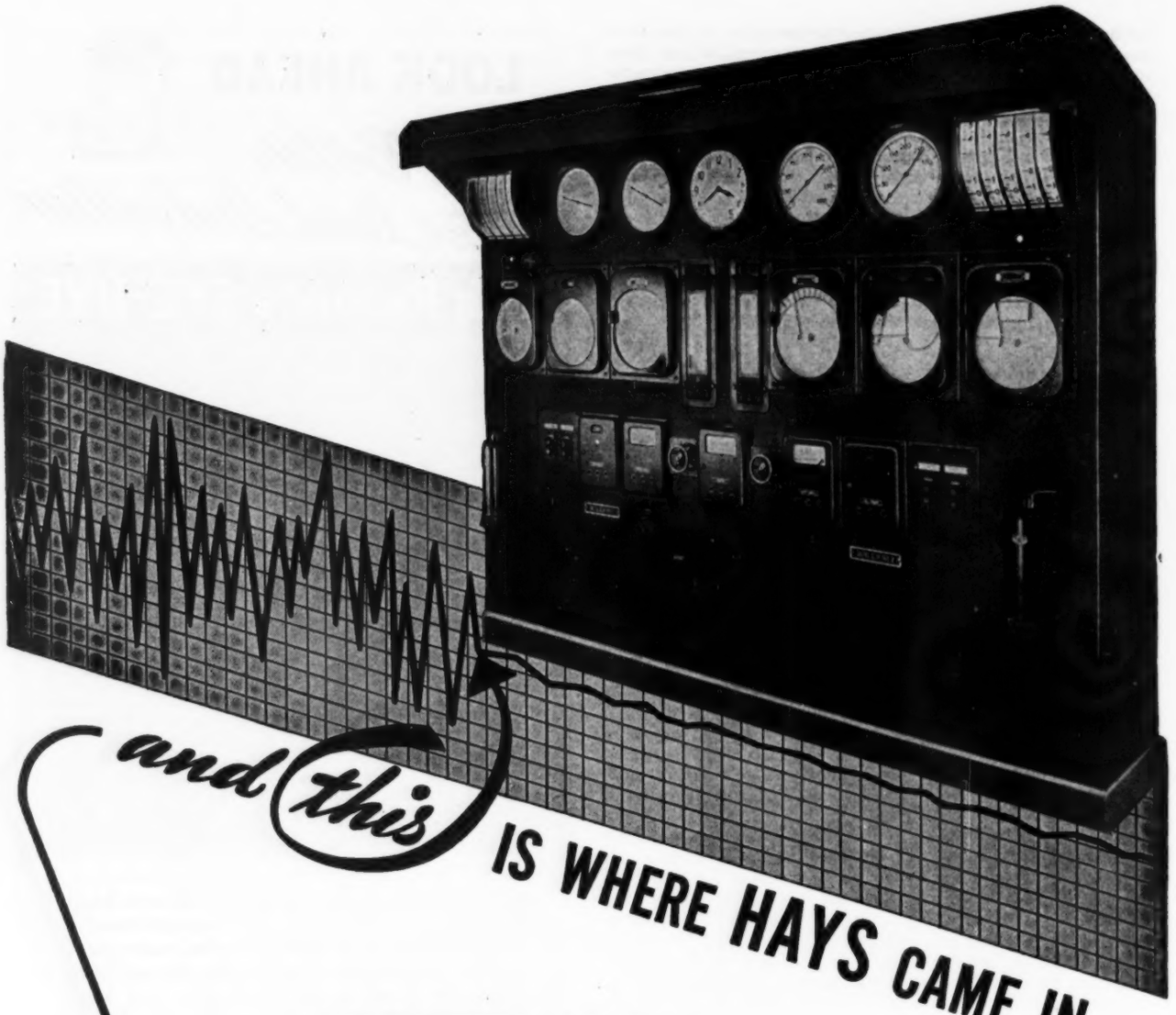

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Methods of Inspection for Pressure Vessels and Piping*

By W. D. HALSEY, Chief Engineer, Boiler Division,
The Hartford Steam Boiler Inspection and Insurance Co.

The author reviews the applications and limitations of various forms of inspection to determine the soundness of welds. These include visual inspection, X-ray and gamma-ray examinations, sampling at selected points along the weld and the employment of magnetic powder. Above all, he stresses the importance of competence on the part of the welder.

THE available methods of inspection of welding, namely, visual, radiographic, sampling and magnetic powder, are all applicable, in at least some degree, to pressure vessels and to piping. In fact, some of these methods are mandatory in the widely recognized construction codes such as the A.S.M.E. and the A.P.I.-A.S.M.E. Pressure Vessel Codes. Except for the specific requirements of such codes, any decision as to what method of inspection should be followed must be based on the nature of the information desired.

It may be presumed that the principal objective in the inspection of welding is to determine that the weld is sound. By that is meant that the welded joint has satisfactory penetration, is well fused and is free from objectionable or harmful slag inclusions, cracks or porosity. It is, of course, necessary that in some way it be determined that the weld metal is of satisfactory tensile strength and ductility and that the base material has not been injured by the process of welding. Information of this nature can best be determined by the adoption of proper welding practices that have been developed by proper research or by long usage so that experience has shown them to be satisfactory. The weldability of the base material should be known and the suitability of the electrode to be used must be well established. In many instances, such as in the case of the construction codes previously referred to, it is necessary that the fabricator establish his method of welding giving consideration to all essential variables and that a test then be made to determine that such method may be expected to produce welded joints of acceptable tensile strength and ductility. In some cases, for instance in the A.S.M.E. Boiler Code and for certain types of vessels in the Unfired Pressure Vessel Codes, specimen welds must be made and tested for each vessel.

The developments in metal arc welding that have taken place in the last decade are such that there now exists a rather extensive knowledge of what constitutes good welding practice to obtain weld metal of satisfactory tensile strength and ductility and to avoid injury to the base material, so that inspection of welding today is focused not so much upon the question of tensile strength and ductility as it is upon the soundness of the weld.

Visual Inspection

The visual method of inspection for soundness of welds is applicable primarily only while the weld is being made. While the contour of a finished weld may furnish some information regarding its probable soundness provided, of course, that there is definite knowledge of the manner in which the parts were prepared for welding, such surface inspection cannot be expected to give any positive knowledge of the soundness of a weld. Unfortunately, a weld that "looks all right" on the surface may be a very unsound one.

Visual examination of a weld as it is made affords an opportunity to determine that the parts have been properly prepared for welding, that acceptable materials are being used, that the welding operator is keeping the weld free from serious slag inclusions and that the weld is being fused to the base material. It has been shown that the visual method of inspection is productive of very reliable results provided competent welding operators are used, the inspector is capable, and the inspection is extensive enough to watch every inch of the welding. Such inspections, sometimes referred to as "man-to-man inspections" require an inspector for every welding operator and are thus expensive. On the other hand, a somewhat less exacting program of inspection, but based upon the use of competent welding operators as determined by test, supervision by competent foremen and check inspections from time to time to see that proper practices are being followed, has been productive of a grade of welding that has proved itself reliable for a great many classes of service.

Radiographic Methods

The radiographic inspection of welding may be carried out by the use of X-ray or by gamma-ray. The former is accomplished by the use of an X-ray tube and the latter by the use of a capsule of radium or of radium emanation.

The X-ray method is most generally applicable in the shops of manufacturers of pressure vessels although some X-ray examinations have been made in the field. However, such application of the X-ray method in the field is

* A paper presented at the 24th Annual Meeting of the American Welding Society, Chicago, October 18–21, 1943.

limited because of the bulk of the equipment involved. On the other hand, the gamma-ray method involves equipment of relatively small bulk.

The radiographic method of inspection is most suitable on butt welds where both sides of the weld are readily accessible. The method is less applicable to welds attaching nozzles to shells.

Either method of radiographic examination as commonly used furnishes a record on a photographic film and the principle of either one is that any defect such as a slag inclusion, porosity, certain types of cracks and serious lack of fusion do not absorb the penetrating ray to the same degree as solid weld metal or the base material and thus these defects are shown on the film as dark areas. The interpretation of such evidences on the radiographic film is not too difficult to make but does require some degree of experience.

It appears that there has been some tendency to view radiographic methods of inspection as being quite complete. Nevertheless, it is believed that all those who have had experience with this method of examination will agree that there are certain types of cracks or lack of fusion that are not detected by X-ray examination as ordinarily applied. With particular reference to cracks it should be understood that the plane of the crack must be parallel to the penetrating ray or, at least, nearly so. Fortunately a crack that is of any depth in a butt weld will usually be in that plane and can, therefore, be detected by radiographic examination, although careful radiography is necessary as is also close examination of the radiographic film.

Inspection by Sampling

The sampling method of inspection of welding may be carried out either by the trepanning of plugs or by the removal of a boat-shaped specimen as is accomplished by the use of a piece of equipment known as a "Weld Prober."

Either of these methods removes samples from the welded seams at selected points. These may be locations that are definitely under suspicion or they may be selected at random to get an idea of the average quality of the weld or to exert a psychological pressure upon the welding operator that any part of the weld that he makes may be so examined. Of course, when used in this manner the welding operator should know in advance that such an examination will be made of his welds.

When plugs are removed by trepanning, the hole so made is sometimes closed by a threaded plug which may be seal-welded for tightness if so desired or a plug may be welded into the hole. There has been some objection to this method of examination when the hole is closed by welding, as some have felt that severe stresses are set up by welding in a constricted place.

The boat-shaped specimen removed by the Weld Prober provides material that can be tested in several ways such as for soundness, for tensile strength and for ductility. The opening left in the weld is similar in many respects to a welding groove and thus lends itself readily to rewelding without great difficulty.

Use of Magnetic Powder

The magnetic powder method of inspection involves the magnetizing of the portion of the weld to be examined and then applying a suitable paramagnetic powder, such as iron filings, to the surface. When properly magnetized the powder will gather at any crack that extends to the surface and may also, by a similar indication, reveal subsurface defects provided they are not too far below the surface and provided they are of sufficient magnitude to maintain the magnetic field at the surface which will hold the powder in contact with that surface.

Inasmuch as cracks which develop in welds as they are being made are one of the most serious types of defect that may be encountered and are frequently difficult to detect except upon a most minute examination, the magnetic powder method of inspection is valuable for use as a weld is being made to insure that no cracks exist in a given layer of welding before the subsequent layer is deposited. In many instances this method of inspection has been used for each layer of welding as applied, or where radiographic methods were not available, and in many instances cracks have been found which were repaired before further welding was done.

As our experience with welding and its application to more extensive fields increases, the probability of defective work decreases provided, of course, that those who use welding understand its fundamental principles and what must be done to insure good work. This means further that intelligent foremen and supervisors are necessary and that honest and competent workmen are employed to do the work. Where such intelligence and honesty are applied inspection becomes less necessary than in the case where slipshod methods and short-change practices are the vogue.

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More About Marine Power Plants

Due, perhaps, to the widespread general publicity that has been accorded shipbuilding accomplishments in this country, COMBUSTION has received numerous inquiries concerning the marine power plants involved. Some of these inquiries have come from those engaged in operating stationary plants, while others have been from engineers who are contemplating entering the marine field. Therefore, the following notes were prepared by Alan J. Ruch, Service Engineer, Combustion Engineering Company, to provide a general idea of the steam power plants installed on the C class of cargo vessels and tankers, together with some of the operating conditions normally encountered. A previous article, in May 1942, covered the power plant of the Liberty Ship.

THE Liberty Ships have been built in fabulous numbers and most remarkable records set for speed in assembling them. Much has appeared in print concerning these ships. While less spectacular records have been set in the construction of the C2 and C3 design cargo vessels being built under the United States Maritime Commission program, these, together with the recently designed Victory Ships, are expected to be the mainstay of our merchant fleet after the war. They are definitely not an emergency design; are capable of maintaining speeds of 15 to 18 knots; and have sizable refrigerated cargo holds as well as air-conditioned holds, making it possible to handle and transport any kind of cargo at a respectable speed.

Stationary engineers who have not had the opportunity of inspecting these vessels may be interested in a brief description of their power plants, a rough idea of the physical dimensions and of the conditions under which the plants operate.

The C2 and C3 cargo ships and the steam-driven tankers have, in general, similar types of power equipment; they operate on the same general initial steam conditions at the throttle and the same heat cycles, differing only in details and in the shaft horsepower developed. The cargo ships are nearly all built with geared turbine drives, whereas many of the tankers have turbine-electric drives. These ships have a single machinery compartment in which the main propulsion turbine, boilers, and the auxiliary power plant equipment are placed. This compartment is roughly 60 by 60 ft and contains a small machine shop and tool room in addition to the plant equipment.

For the sake of brevity, this discussion will be confined to the C2 design of cargo vessel.

These vessels are equipped with a single cross-compound turbine direct-connected to the propeller shaft through a reducing gear. Two boilers are employed, each generating approximately 25,000 lb of steam per hour at normal power. Auxiliary turbine-generators furnish the power required for motor-driven auxiliaries and the ship's lighting. Steam conditions at the turbine throttle are 450 lb gage and 750 F total temperature.

A reversing turbine capable of developing about 60 per cent of the shaft horsepower of the main turbine is built into the same casing. This must be dragged by the main turbine at all times when the ship is moving ahead; it cannot be disconnected as it must be ready for instant use in emergencies. The reversing turbine is a complication not encountered in stationary plants and is one of the necessary evils of a geared-turbine-driven ship.

Two boilers are installed in each ship, both the cross-drum sectional header and the vertical bent-tube designs being in use. Water-wall furnaces are used on both types of boiler. The former (Fig. 1) are set with the drums fore and aft, the firing fronts facing each other at a firing aisle amidship, and the oil burners under the downtake headers. The latter (Fig. 2) are set back-to-back with the gas uptakes together amidship, and the oil burners are placed in the furnace sidewall to make a firing aisle running athwartship.

Heat-recovery equipment consists of either economizers, air heaters, or both. The air heaters are a tubular type with horizontal tubes, the gas sweeping over and the air passing through the tubes. A two-pass counterflow arrangement is nearly always employed, this being accomplished by using a turning box at one end of the heater. Air enters half the tubes, passes through to the turning box and comes back through the other half so that air enters and leaves at the same end of the heater. The important consideration here is the space required by the air heater and the connecting ductwork.

The conventional types of steel-tube economizers are installed. The superheaters in the bent-tube boilers are arranged with horizontal tubes.

Tube sizes for marine boilers are smaller than those commonly used in stationary types. A bent-tube boiler for a C2 vessel would have 2-in. tubes for the water-walls and the three rows of boiler tubes in front of the superheater. Tube rows behind the superheater are usually $1^1/_2$ in. Superheater and economizer tubing is $1^1/_4$ in. or $1^1/_8$ in. and air heater tubing $1^1/_2$ in.

The superheater and economizer elements are connected to the headers with rolled joints. Welded joints are not entirely practical because of the close tube spacing and comparative inaccessibility. Another important consideration is that repair or replacement of a rolled joint element can be done by any fairly good mechanic which is not the case with a welded joint element.

The boilers are arranged for oil firing, forced-draft oil burners with mechanical atomizers being used almost exclusively.

The forced-draft blower is connected to the burner wind-box by a closed duct, for the pressure fireroom is economical only with a multiplicity of small boilers. Use of double casings is common, the combustion air from the blower being passed through the space between the casings. This helps to reduce radiation loss from the setting and eliminates gas leakage into the machinery space.

Induced-draft fans are not used. The furnaces are operated with a pressure of 2 to 4 in. w.g. at normal steaming rate. The saving of space and the simplified breeching construction justify the added cost of the gas-tight boiler casings.

Except for the Liberty Ship, automatic combustion control and feedwater regulators are being installed in all the cargo vessels. The air-operated types are favored because the installation is fairly simple. Oil hydraulic types are regarded as a fire hazard.

Since no induced-draft fan is installed the combustion control requires only two power units, a damper control for forced draft, a control valve for fuel oil, and a ratio controller for each boiler. The ratio control is designed to allow quick readjustment for the various sizes of atomizer tips required for the operation of the ship.

The feedwater regulators are usually of the single element types with various methods of controlling the excess pressure depending chiefly on the type of feed pump and feed pump drive.

The steam piping arrangement is quite different from that common to stationary practice. The boiler non-return valve is usually placed in the steam line some distance from the superheater outlet nozzle. Between the nozzle and the non-return valve connections are made for the auxiliary steam line (superheated to the auxiliary turbine-generators), the desuperheater, the soot-blower supply, the superheater safety valve, the various instrument taps for temperatures and pressure gages and combustion control. Also, from this manifold is taken a vent line to the atmospheric exhaust to be used to maintain a flow of steam through the superheater while the boiler is being fired to raise steam pressure.

Generally, the auxiliaries such as deck winches, cargo pump, auxiliary feed pump, etc., are steam-driven and use low-temperature steam from a submerged-type desuperheater located in the boiler drum. The desuperheated steam is also used on the steam-smothering system for fire protection in the cargo spaces.

The feedwater system is usually duplicated, at least to the connection to the boiler or economizer, and often to the extent of two feedwater nozzles on the boiler. Either the main feed pump (motor- or turbine-driven) and the auxiliary pump (vertical simplex) have capacity for supplying the feedwater for full load. In addition a port, or standby, pump is often installed for port service. Many ships are built with a main and auxiliary feed pump for each boiler with no cross-connection; in others the main and auxiliary feed pumps serve both boilers.

Deaerating heaters and stage heaters are employed and the final feedwater temperature is around 240 F. Makeup feedwater is evaporated.

The fuel-oil system, as far as the fuel-oil pumps and heaters are concerned, is little different from that found

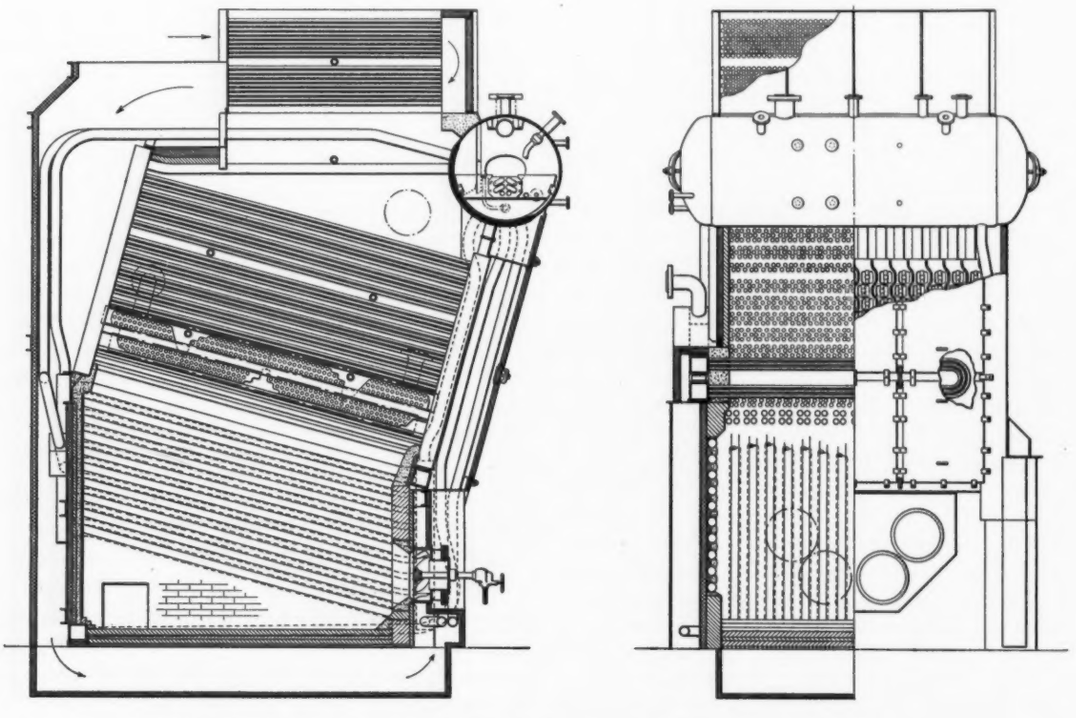


Fig. 1—Section through typical cross-drum sectional-header boiler

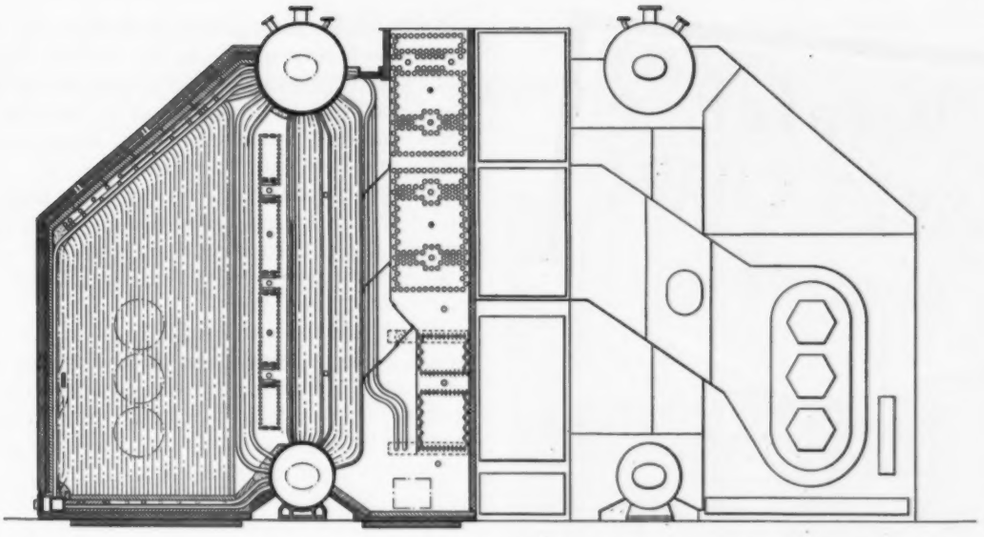


Fig. 2—Showing usual arrangement of two-drum bent-tube boilers set side-by-side with dividing wall

in stationary plants. Fuel-oil storage is in numerous tanks arranged in the hull and in the ship's double bottom. Some of these tanks may be used for liquid cargo when necessary.

Care must be exercised in taking the fuel oil from the storage tanks to maintain the proper trim of the ship. Often it is necessary to fill empty tanks with sea water to ballast the ship and maintain trim. This often results in getting the fuel oil mixed with sea water. Therefore, settling tanks are necessary to separate such mixtures. The fuel oil is pumped from the storage tank to one of two settling tanks and allowed to stand, fuel being pumped alternately from these tanks to the fuel-oil heaters and burners.

Among the auxiliary equipment installed are duplicate turbine-generator sets to provide the electric power for ship's lighting and for motor-driven auxiliaries. Direct current is widely used. The turbines operate on superheated steam, the throttle conditions being the same as used on the main turbine. An auxiliary condenser takes care of the exhaust from the turbine as well as from other steam-driven auxiliaries.

A small diesel generator set is nearly always installed to supply starting power in case both boilers are cold.

The forced-draft blowers, the main feed pumps, fuel oil pumps, condensate, and circulating pumps are often motor driven. In addition to these power plant auxiliaries other equipment in the ship may be motor-driven, such as cargo winches, the refrigerating, air conditioning, and ventilating systems.

Evaporators and distillers are needed for the ship's fresh water and potable water needs.

Pumps of several kinds are needed. In addition, those classed as power plant auxiliaries, are fire pumps, bilge pumps, transfer pumps for fuel oil and for liquid cargo, evaporator feed pumps, sanitary pump (sewage must be pumped overboard), also fresh water, and potable-water pumps.

Operating Conditions

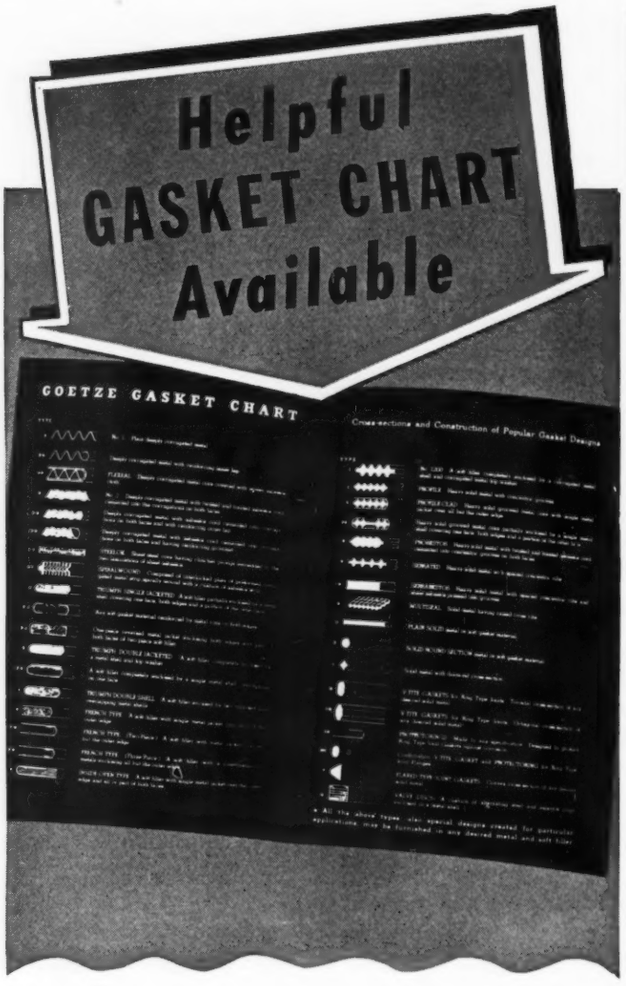
The operating conditions may be divided into five classifications: (1) port, (2) standby, (3) maneuvering, (4) normal steaming, (5) emergency or overload steaming.

In port the ship will be discharging and loading cargo. One boiler will be in service to supply steam for an auxiliary turbine-generator, the boiler auxiliaries, the cargo-handling gear, cargo pumps, ballast pumps and refrigerators, fire pump, etc. The boiler load at this time may be between 5 and 25 per cent of the normal steaming capacity, depending on the cargo being handled. The other boiler will ordinarily be out for any necessary inspection, cleaning and repair work. In ports in active war zones the ship must be on "standby" condition which may make necessary the postponement of badly needed cleaning or repair work.

When the ship is ready to be moved on instant notice the power plant will be at "standby." Both boilers will be at normal pressure and cut into the line. The main turbine is warmed up ready to start and the main condenser circulating and condensate pumps will be in service. At this time the steam demand will be about 10 to 15 per cent of the normal steaming capacity depending on the amount of cargo refrigeration and air conditioning required.

During the "maneuvering" condition while the vessel is being worked out of the harbor to sea, the main propulsion unit is being operated at various speeds both "ahead" and "astern," on signals from the bridge. In general, the maximum power called for at this time is about 60 per cent of normal but the plant must be ready at all times to deliver full power on signal.

Signals from the bridge must be followed immediately; there is no possibility of advance warning. The plant load will vary sharply and frequently between the 10 to 15 per cent "standby" steam demand to 65 to 75 per cent normal demand or even to normal demand. Maneuvering also requires the main turbine (or other propulsion unit) to be changed in speed or direction as rapidly as the throttle can be handled. It is not unusual to change the turbine from two-thirds normal speed ahead to full speed astern (equal to two-thirds ahead) as quickly as the ahead throttle can be spun shut and the astern throttle opened—about fifteen seconds in total time.



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As the ship clears port it is brought up to its normal speed which corresponds to the normal full power of the plant. Except in bad weather, such as fog or heavy seas, the vessel will be operated at a constant speed until again entering a harbor. The steam demand varies only minutely during this time.

Emergency conditions may require taking one boiler out of service at sea. The boilers are designed for 150 per cent of the normal capacity so that in case one boiler must be shut down the vessel can maintain a fair speed on the remaining boiler.

The problems confronting the operators are many and varied. They include varying sources of fuel supplies. A ship on one voyage may have to take oil at two or more ports enroute. The oil available may be anything from diesel oil to heavy residues and, to make matters worse, it may have to be mixed in the tanks.

Smoke a Double Hazard

Smokeless operation is a necessity. Municipal smoke ordinances must be observed while in port, a familiar problem for stationary engineers. At sea, in wartime, the safety of the ship depends on smokeless operation. A ship with a trail of smoke behind it can be spotted much easier by an enemy sub or plane, even at night. The danger of making visible smoke prevents the regular operation of soot blowers so that trouble is often encountered with dirty boilers and considerable manual cleaning is needed when a boiler can be cooled down in port.

A ship once clear of port is entirely on its own. There is no such thing as telephoning for a service engineer to assist with any operating trouble, and no way to obtain a badly needed spare part that is not in stock. Obviously, the ship's engineers must keep comparatively complete inventories of important spare parts and tools in stock. Steamship safety laws and insurance requirements specify many minimum spare part and tool requirements. All important motors, for instance, must have a spare armature and field coils that are carried in stock on the ship.

Personnel problems also rate high in importance. As long as ships have sailed it has been customary to sign on a crew for one voyage only. At the completion of that voyage, the crew is paid off. When shipping is active and men are in demand this results in a high turnover in operating personnel. The licensed personnel is likely to remain with the ship, but sometimes it has been necessary to start a ship on a voyage with a complete new engine-room crew put aboard less than twenty-four hours before sailing.

Stationary engineers can imagine the turmoil that would exist in many well-operated plants if the operating force were changed every two or three months.

The maintenance work constitutes a problem because, obviously, a plant of the cargo ship size cannot economically support a full-time maintenance force comparable to those found in the larger stationary plants. Therefore, except for minor repairs and emergency work needed at sea, maintenance work is done in port. Repair shipyards handle the great bulk of such maintenance work, on contract or cost-plus agreements.

From the foregoing it will be seen that although the marine power plants are relatively simple they present problems quite different from stationary practice.

Program of A.S.M.E.

SIXTY-FOURTH ANNUAL MEETING

The largest and most varied program ever announced for an A.S.M.E. Annual Meeting is to be held at the Hotel Pennsylvania, New York City, during the week of Monday, November 29, through Saturday, December 4. Practically every professional division and many technical committees are represented on this program. In the field of steam generation an unusually interesting program is promised covering such topics as: Fuels, Furnace Geometry, Furnace Performance Factors, Thermodynamics, Boiler Feedwater Studies, High-Temperature Steam Corrosion, Power Consuming Equipment for Ships, together with a symposium on Boiler Fan Selection and Use and a panel discussion on Heat Transfer Experimental Techniques.

Numerous papers reflecting the background of the war and the concerted effort being made to retain superiority and leadership in equipment and production are apparent in many of the sessions, but particularly so in those devoted to Aviation, Applied Mechanics, and Education and Training.

Luncheons sponsored by the Management, Aviation, Railroad, and Wood Industry Divisions are scheduled each day from Tuesday to Friday, respectively, and the 1943 Annual Dinner will be held in the ballroom of the Hotel Pennsylvania on Wednesday evening, December 1. Reservations for these events, for train travel and hotel accommodation should be made as early as possible.

Technical papers and discussions dealing with subjects relating directly or indirectly to power plant problems are as follows:

Monday, November 29

8:00 p.m.

FURNACE PERFORMANCE FACTORS (I)—POWER

"Operating History of the 2500-Psi Twin Branch Plant," by Philip Sporn and E. G. Bailey.

"Natural Circulation Test Results in the 2500-Psi Twin Branch Boiler," by W. H. Rowand and T. B. Allardice.

"Distribution of Heat Absorption and Factors Affecting Performance of the Twin Branch 2500-Psi, 940 F Boiler with Reheat to 900 F," by E. G. Ely and L. B. Schueler.

FUELS (I)

"Combustion of Barley Anthracite," by Allen J. Johnson.

"New Combustion Methods for All Standard Fuels," by Robert Reed.

Tuesday, November 30

9:30 a.m.

THERMODYNAMICS—FLUID MECHANICS

"Nozzles for Supersonic Flow Without Shock Fronts," by A. H. Shapiro.

"Oscillations in Closed Surge Tanks," by A. M. Binnie (to be presented by H. W. Emmons).

"The Second Law of Thermodynamics for Changes of State and Quantity of the Working Substance, with Particular Reference to Steam Engines," by the late G. Zerkowitz (to be presented by J. H. Keenan.

"Heat Effects in Lubricating Films," by A. C. Hagg.

HIGH-TEMPERATURE-STEAM CORROSION

"High - Temperature - Steam Corrosion Studies in Detroit," by I. A. Rohrig, R. M. Van Duzer, Jr., and C. H. Fellows.

"The Corrosion of Alloy Steels by High-Temperature Steam," by G. A. Hawkins, J. T. Agnew, and H. L. Solberg.

2:00 p.m.

BOILER FEEDWATER STUDIES

"A New Approach to the Problem of Conditioning Water for Steam Generation," by R. E. Hall.

FUELS (II)

"Combustion in High-Pressure Chambers," by Eric G. Peterson.

"An Evaluation of the Importance of Physical and Chemical Properties of Fly Ash in Creating Commercial Outlets for the Material," by C. M. Weinheimer.

"Fuel and Its Research in England During the War," by W. C. Schroeder.

8:00 p.m.

SYMPOSIUM

"Boiler Fan Selection and Use." Participants: W. S. Patterson, M. S. Kice, H. F. Hagen, P. S. Dickey and J. J. Grob.

Wednesday, December 1

9:30 a.m.

FURNACE PERFORMANCE FACTORS (II)

"Furnace Geometry of Large Furnaces," data by R. J. Brandon and W. A. Carter, H. Weisberg, J. H. Harlow, W. E. Caldwell, P. Sporn, J. R. Michel, and a summary by A. R. Mumford, Chairman of the Committee.

2:00 p.m.

POWER (I)

Report of Joint A.I.E.E.-A.S.M.E. Committee on Tentative Specifications for Speed Governors.

Thursday, December 2

9:30 a.m.

FURNACE PERFORMANCE FACTORS (III)

"Heat Transfer in Furnaces," papers by Henry Kreisinger and R. C. Patterson.

"Heat Transfer in Separately Fired Radiant Superheaters," by John Blizard.

"Physical Properties of Slags," by W. T. Reid and T. Cohen.

Thursday, December 2

2:00 p.m.

GRAPHITIZATION OF STEEL

Papers on the Graphitization of Steel Piping.

APPLIED MECHANICS—SESA (II)—POWER

"Bursting Tests of Steam-Turbine Disk Wheels," by E. L. Robinson.

HYDRAULICS (I)

"Hydraulic Torque Converter," by A. Lysholm.

"Mechanical Details and Performance Tests on 30,000-Hp Glenville Unit, The East's Only Large Impulse Turbine," by Arnold Pfau.

8:00 p.m.

HYDRAULICS (II)

"Maintenance of Hydroelectric Generating Units," by G. H. Bragg.

"Hydraulic Turbine Maintenance," by G. R. Woodman.

HEAT TRANSFER PANEL DISCUSSION ON EXPERIMENTAL TECHNIQUES

Discussion on Experimental Determination of Mixed-Mean Fluid Temperatures.

Discussion on Special Arrangements for Testing Heat Exchangers.

Motion Pictures Illustrating Visual Techniques in the Study of Heat Transfer.

POWER CONSUMING EQUIPMENT FOR SHIPS

"Centrifugal Feedwater Pumps," by Arvid Peterson.

"Steam Jet Vacuum Pumps," by Robert M. Rohrbaugh.

"Air Compressors," by William T. Alderson.

"Circulating Pumps," by C. R. McBath.

"Heat Exchangers," by H. E. Carlton.

Friday, December 3

9:30 a.m.

POWER (II)

"Theoretical Regenerative-Steam-Cycle Heat Rates," by A. M. Selvey.

"Fluid Flow Through Two Orifices in Series," by M. C. Stuart.

2:00 p.m.

POWER (III)

"Investigation of Blade Characteristics," by John Weske.

"Notch Toughness Tests of Carbon-Molybdenum Piping Material," by W. F. Kinney.

Ralph S. Damon, American Air Lines, will deliver the principal address, "Aviation During and After the War," at the 1943 Annual Dinner. Honors and awards for 1943 will also be presented at the dinner and a number of distinguished engineers will receive certificates of honorary membership.

A feature of the 1943 Annual Meeting will be an exhibition of some 45,000 U. S. patents, formerly enemy-owned or enemy controlled, in the mechanical, electrical, and chemical fields. These patents have been taken over by the Office of Alien Property Custodian of the U. S. Government and are available for licensing on liberal terms.

Annual Water Conference

The Engineers' Society of Western Pennsylvania held its Fourth Annual Water Conference at the William Penn Hotel, Pittsburgh, November 1 and 2. This comprised an extensive program of papers and panel discussions on water technology, including feedwater, water conditioning for various purposes and corrosion.

The first paper, by **Owen Rice,** reported the results of laboratory tests on the inhibitive action of Calgon. Using Pittsburgh water and steel specimens, these tests were conducted under conditions of agitation, aeration and stagnation. With stagnant water, the corrosion rate was considerably slower than when the liquid was agitated or aerated, but when 25 ppm of Calgon was added to a liter of the liquid, corrosion was inhibited despite agitation or aeration.

The volume of the solution was found to have important bearing, for with 20 liters of water only one-tenth the quantity of Calgon was required to produce the same effect as with one liter. However, velocity proved to be a factor as the Calgon did not become effective until the velocity of the liquid passing the specimen exceeded 4 ft per sec.

Other tests demonstrated the effect of temperature, the rate of corrosion of the steel increasing up to about 80 C (176 F) with the untreated water, but when 10 ppm of Calgon was present in 20 liters of solution, the corrosion rate for corresponding temperatures was lowered considerably.

The second paper, by **R. C. Adams,** described the procedure employed at the U. S. Naval Engineering Experiment Station, Annapolis, in approval testing of deaerating feedwater heaters. The author pointed out that the general use of integral economizers by the Navy makes it necessary to deaerate the feedwater completely and that deaerators must be employed for this purpose as other means are not practicable aboard naval vessels. The laboratory tests were arranged to simulate as closely as possible actual operating conditions afloat.

Another paper having interest for the power plant field was "Some Characteristics of Acid-Regenerated Carbonaceous Zeolites," by **F. N. Kemmer** and **Joseph Thompson,** research engineers of the Cochrane Corporation.

Mr. Thompson gave an excellent survey of the development of zeolites for feedwater treatment. The original greensand zeolites had a low exchange capacity necessitating frequent regeneration. The synthetic zeolites made of sodium aluminate and sodium silicate gave a higher exchange capacity but the pH of the water had to be controlled closely to prevent excessive silica in the boiler water. With the development of the carbonaceous zeolites, produced by the action of sulphuric acid or sulphur trioxide on bituminous coal or lignite, a non-siliceous zeolite of high exchange capacity became available.

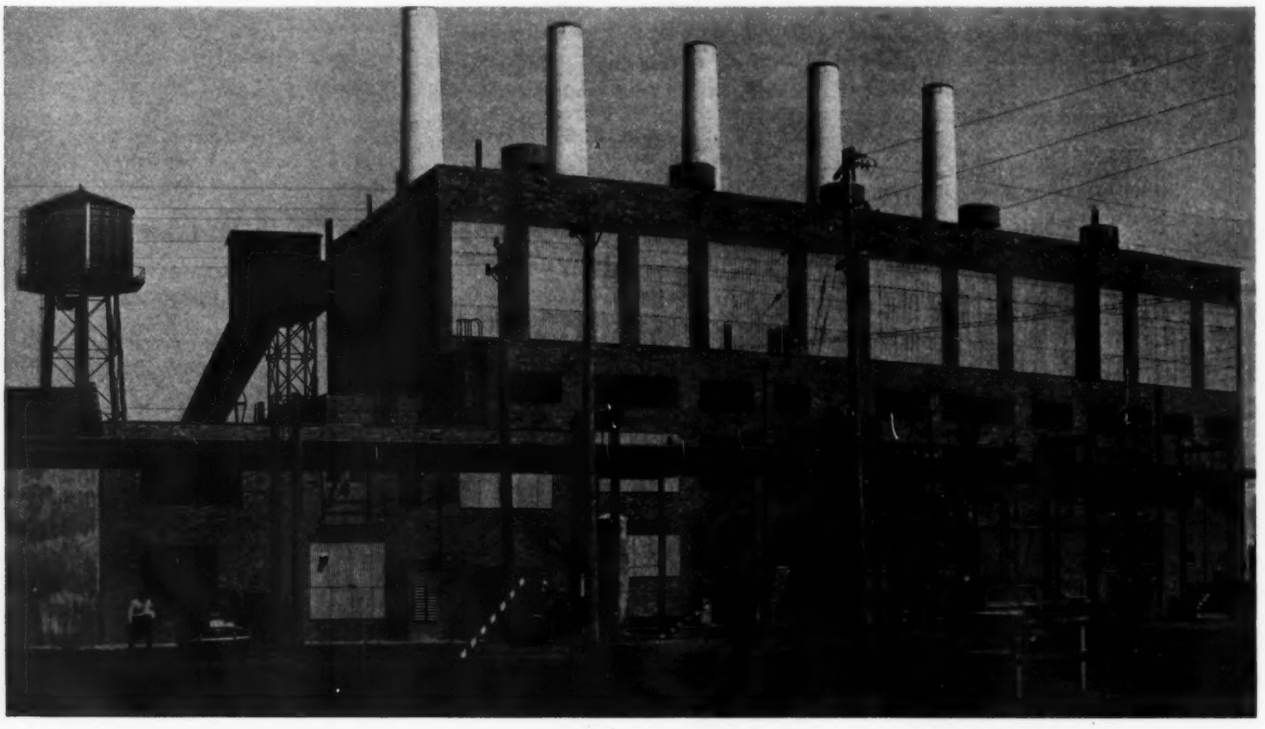
It was brought out that the affinity of these zeolites for various cations is in the following order: Na, NH_4, Ca, Mg and H. The paper was well illustrated with slides showing the results of laboratory tests.

The main point brought out in the subsequent discussion of the paper was that the authors' data were applicable only to the zeolites that they had studied, as zeolites vary widely in their properties.

A second paper dealing with this subject was entitled "Latest Developments in Removal of Cations and Anions from Water by Demineralizing." In the absence of the author, **H. L. Tiger,** of The Permutit Company, the paper was presented by Mr. Miller who reviewed briefly the development of zeolites for water treatment, including the resinous type for anion exchange. He contended that demineralized water is equivalent to distilled water in every respect and less expensive.

Exception to the first part of this statement was taken by some discussors who pointed out that zeolite-treated makeup has no bactericidal action on certain harmful bacteria; also that complete removal of anions and cations might cause the silica, that is not removed, to be deposited as pure silica.

Experimental studies of boiler scale at 800 psi were reported by **J. A. Holmes** and **C. Jacklin,** of National Aluminate Corporation. A small laboratory boiler was employed and the effects of increasing pressures from 100 to 800 psi at three different ratings were investigated with various combinations of calcium, magnesium, phosphate, silica, alumina and a few organic substances. This was accomplished by making up synthetic water and adding one constituent at a time to ascertain the effect of each.



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Power plant serving a large Ordnance Works in the Northwest

American Welding Society Elects Officers

At the recent Annual Meeting of the American Welding Society in Chicago, the following 1943–1944 officers were elected:

President, David Arnott, of the American Bureau of Shipping, who has long been active in affairs of the Society, particularly in technical activities relating to ship welding; 1st Vice President, Isaac Harter, vice president of Babcock & Wilcox Company; and 2nd Vice President, A. C. Weigel, vice president of Combustion Engineering Company. Mr. Weigel has long been a member of the Executive Committee of the Society and of the A.S.M.E. Boiler Code Committee.

In addition to the national officers, the following district vice presidents were chosen:

DISTRICT VICE PRESIDENTS

New York and New England—F. C. Fyke, Standard Oil Development Co., Elizabeth, N. J.

Middle Eastern—C. H. Jennings, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Middle Western—G. N. Sieger, president and general manager, S-M-S Corp., Detroit, Mich.

Southern—E. C. Chapman, metallurgist in charge of welding research, Hedges-Walsh-Weidner Division, Combustion Engineering Co., Chattanooga, Tenn.

Pacific Coast—J. C. Gowing, Southern California representative, Hobart Brothers, Los Angeles, Calif.

The directors at large are: H. W. Pierce, assistant to general manager, New York Shipbuilding Corp.; E. R. Seabloom, supervising engineer, Research and Development Laboratories, Crane Co.; K. V. King, materials engineer, Standard Oil Co. of Calif.; and J. H. Deppeler, chief engineer, Metal & Thermit Corp.

Utility Output Continues to Gain

The Federal Power Commission announced on November 5 that the electric energy output of the principal public utility systems of the country during September 1943 totaled 18,308,504,000 kw-hr which represented a gain of 16.7 per cent over the same month last year. Corresponding peak demands aggregated 35,105,405 kw or 14.1 per cent over September a year ago. Comparable percentage increases reported for the preceding month were 18.5 per cent for energy and 16.5 per cent for demand in comparison with August 1942.

The Commission stated that estimates of 1943 energy requirements made by the Class I electric utility systems in their September reports aggregate 214,861,065,000 kw-hr for the year. Utility estimates of peak demands for December 1943 are reported to amount to 37,724,375 kw. These figures represent increases of some 363,000,000 kw-hr and 92,000 kw, respectively, from similar forecasts submitted by the utilities in their August reports.

The name-plate rating of new generating capacity placed in service during August totaled 351,500 kw. These new installations added 373,400 kw of dependable ca-

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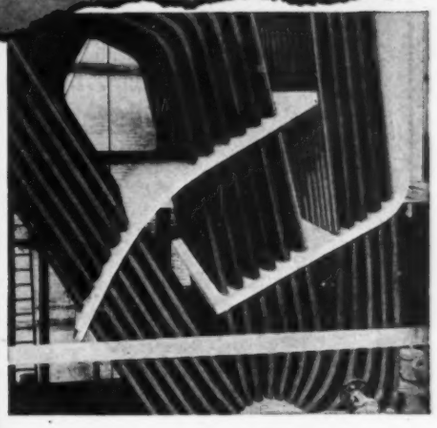

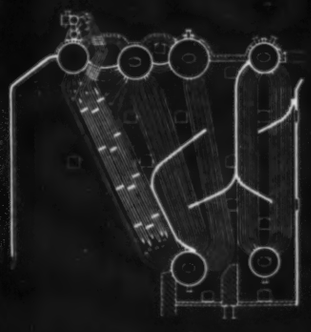

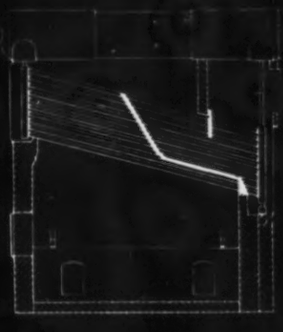

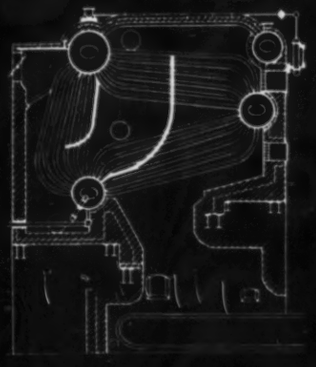

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Scientifically tapered gas passes and curved baffle surfaces put every square foot of heating surface to work, maintain efficient gas velocity, eliminate bottlenecks, eddy currents, dead gas pockets.

Draft losses reduced. Less steam needed for cleaning, because soot blowers work more effectively—and need be used less often with Enco Baffles.

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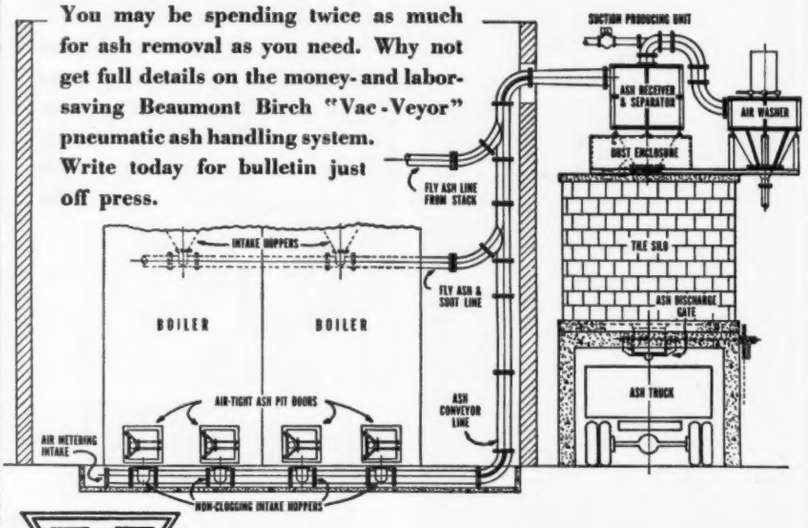

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pacity, and the installation of a new boiler in an under-boilered plant added an additional 13,000 kw of dependable capacity.

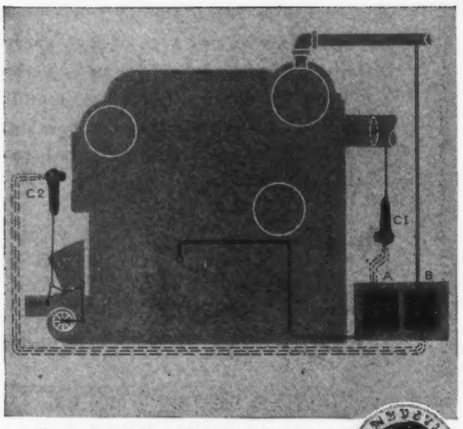
Scheduled net additions to the installed generating capacity of the principal systems are given as 1,150,200 kw by the end of 1943, an additional 1,229,000 kw by the end of 1944, and a further increase of 140,000 kw by December 31, 1945. These figures include only those additions actually on order and authorized by the War Production Board for installation in the year indicated.

E.C.P.D. Officers

Everett S. Lee, of the General Electric Company, was elected chairman of Engineers' Council for Professional Development at its eleventh annual meeting held recently in New York City. Also elected to serve with him, as vice chairman, are James W. Parker, vice president of the Detroit Edison Company; Stephen L. Tyler, executive secretary, American Institute of Chemical Engineers as secretary; and R. L. Sackett, dean emeritus of engineering, The Pennsylvania State College, assistant secretary.

Engineers' Council for Professional Development is sponsored by the major national engineering societies for the purpose of coordinating and promoting higher professional standards of education and practice, greater solidarity of the engineering profession, and greater effectiveness in dealing with technical, economic, and social problems.

Dependable Automatic Boiler Control
AT SURPRISINGLY LOW COST . . . BY HOTSTREAM



Typical installation of Hotstream controls on stoker-fired industrial steam plant. (A) Dampertrol, (B) Steptrol, (C1 & 2) Electric Pistons.

Hotstream engineers designed this line of Combustion Equipment to provide low-priced, dependable boiler control at a cost low enough to be within the reach of every plant, large or small. Results are comparable to those obtained from elaborate, expensive systems—at but a fraction of the cost. Listed as essential fuel-saving devices by W.P.B., they are available now *without priority* . . . Typical installation at left shows how Hotstream Dampertrol (A) regulates uptake damper through Fast Stroke Electric Piston (C1) from changes in overfire draft, while Hotstream Steptrol (B) controls fuel and air supply through Electric Piston (C2) from changes in steam pressure.

HOTSTREAM ALSO OFFERS:

THERMOGAGE . . Electric flue-gas-temperature indicator.
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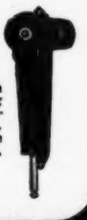
Hotstream Dampertrol . . . control for Electric Piston operating from draft or air pressure.

Hotstream Steptrol, control for Electric Piston operating from steam pressure.



Hotstream Electric Piston for regulating dampers, stokers . . valves . . etc. . . . Made in 3 speeds.

Combustion Equipment Division

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NEW EQUIPMENT

Turbine Reduction Units

A line of standardized, self-contained industrial turbine reduction units has been announced by the Cone-Drive Division, Michigan Tool Company. The line has been developed from the naval turbine reduction units produced for the U. S. Navy. Built around the use of area contact, double enveloping cone-drive gearing, these units are more compact than other forms of right-angle drive gearing of equal load capacity.

The new units are being made available in 26½ and 37-hp base ratings. The former is the output rating of a 4½-in. center distance unit, while the latter has gears of only 6-in. center distance. Both types are designed to operate on input speeds of 5000 to 6000 rpm. The two basic units are available in a selection of standard ratios ranging from 3½ to 8 to one. Self-contained, they are completely equipped with built-in oil pump and oil cooler, oil filter and pressure relief valve, pressure gage, thermometer and oil level gage. The lubrication system is of the force feed type.

Self-Priming Pump

An improved automatically controlled valve is a distinctive feature of the new Type AO self-priming pump announced by Allis-Chalmers Mfg. Co. Priming is accomplished as the motion of the water throughout the pump runner and the volute passage carries behind it a slug of air, drawing air in the suction passage through the impeller and out through the priming chamber. This hydraulic action lifts the column of water in the suction line and achieves the same results as would a separate vacuum pump. The priming valve closes slowly during this process, acting against a spring tension which governs the rate of priming and the static height of the priming suction lift. The automatic closing of the valve after complete priming prevents water from bypassing back to the suction chamber, with resultant power loss.

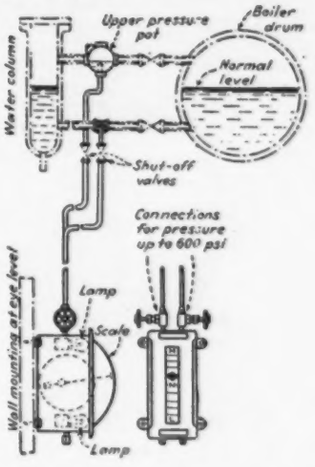
A complete line of these self-priming pumps is planned in from 1 to 6-in. sizes although only 2- and 3-in. sizes are now ready. The entire line of pumps will range from a very small capacity to 1400 gpm and up to heads of 100 ft or over. The self-priming device incorporated in these pumps is also adaptable to use with other pumps, particularly the single-suction type.

Remote Water-Level Indicator

This new instrument, offered by Yarnall-Waring Company, which may be wall- or panel-mounted at eye level, shows the level of water in the boiler drum. It is operated by difference in pressure in connecting tubes (see sketch) which is merely the difference in head between a fixed water level in the upper pressure pot and varying water level in the boiler drum.

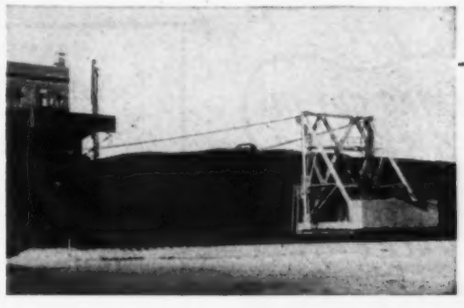
Pressure differential acts on a Neoprene diaphragm and a pin transmits net diaphragm force to a spring-metal deflection plate, moving a powerful permanent magnet along a bronze alloy tubular well containing a spiral armature of magnetic material. Thus rotation of the armature, and corresponding greatly magnified motion of the pointer, is in direct proportion to movement of the diaphragm, actuated by changes in static head.

The magnetic principle permits complete separation of pressure parts from non-pressure parts without stuffing boxes. Thus the magnet and deflection plate are in the pressure chamber, whereas the jeweled-bearing armature in the tubular well operates freely without packing and at atmospheric pressure.



A balanced black pointer, attached to the armature and revolving with it, registers changes in boiler water level on an illuminated scale that shows green for normal operating range and red at high and low levels. An adjusting screw changes the scale range by shifting the fulcrum of deflecting plate; another adjusts the instrument zero.

Two models serve all boiler pressures up to 1500 psi.



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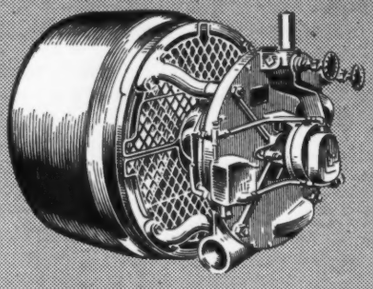

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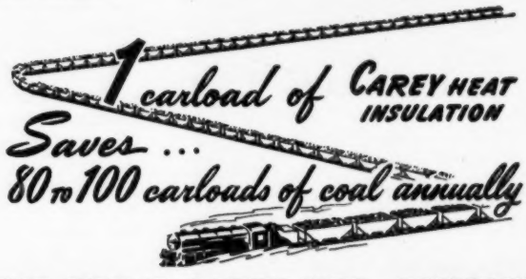

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